ENVIRONMENTAL FACTORS INFLUENCING THE DISTRIBUTION OF BATS (CHIROPTERA) IN SOUTH AFRICA

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I dedicate this thesis to my daughter, ‘Saada’, who showed up in this world in the middle of this work. You are an angel to me ‘Saada’ and I hope that I will be up to the challenge to be a good father to you.

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DECLARATION

I declare that this thesis is my own independent research, both in notion and implementation, and that apart from the usual guidance from my supervisor, I have received no assistance unless where explicitly mentioned in the text. Neither the material nor any part of this thesis has been submitted in the past, or is being, or is to be submitted for a degree at any other university. I am now submitting this thesis for examination for the degree of PhD at the Zoology Department, Science Faculty, University of Cape Town, South Africa.

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ABSTRACT

Environmental factors limiting the distribution of 37 of the 56 bat species in a warm temperate region (South Africa) were determined using GIS software and the Maximum Entropy modelling technique (MaxEnt). Undertaking such a study in a warm temperate region like South Africa is essential as the outcomes of this study could inform our general understanding of distributions of other animals in other parts of the world. Hypotheses related to the ecological niche-based characteristics of species were tested to identify the most important variables influencing the distribution of South African bats and to predict the probability of occurrence for bat species in South Africa. A database that included locality records for bat species from different museums in South Africa was compiled and then combined with the researcher's own data for the Northern Cape Province as there was insufficient knowledge of bat distributions in this province. A total of 23 environmental variables were considered, of which 20 were downloaded from the WorldClim database as potential environmental variables influencing the contemporary distribution of bats in South Africa based on previous studies that use environmental variables from WorldClim to predict the distribution of species. The environmental variables were grouped into broad categories, temperature, precipitation, and biophysical (i.e., vegetation biomes, land use/land cover, geology) variables. As predicted, taxonomic affiliations appear to have no bearing on which factors influenced the geographic distribution of South African bat species. The distributional limits of even closely related species within the same genus appear to be influenced by disparate environmental factors. Geology appeared to be the most important limiting factor for 15 of the 37 species, all of which are known to use roosts associated with geological features (i.e., caves, mines and rock crevices). Land use/land cover influenced the distribution of six bat species most of which are known to use human structures or domesticated crops as roosting sites. Roost availability thus appeared to be an important factor limiting the distribution of bats. The distribution of only one South African bat species, the endemic *Rhinolophus capensis*, was associated with a biome as being the most important predictor variable. Temperature variables appeared to be the most important factors influencing the distribution of 12 of the 37 species of bats in South Africa. This might be linked directly to the roosting ecology and thermoregulation capability of each species and their need for hibernation and/or torpor. Precipitation parameters were the most influential in the distribution of 9 of the 37 South African bat species whose distribution is centred towards the wet east of the country. This could probably be linked to its effects on the availability of food in the form of fruit or insects. However, the results of this study should be interpreted cautiously. The majority of the environmental variables employed in this study to model the distribution of bats, were correlated to some degree, which could affect the contribution of an individual environmental variable to the performance of a model. Furthermore, certain bat species included in this study have their centres of distribution ranges further north in Africa and have only marginal intrusion into South Africa's political boundary, which means that only a portion of the distribution of these species is modelled; this could yield erroneous results that might not be transferable to other parts of the ranges of these species. Finally, field verification of the occurrence of species in areas where they are predicted to have a high probability of occurrence is crucial in order to verify the reliability of the models.

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Chapter 1

INTRODUCTION AND LITERATURE REVIEW

The geographic distribution of a species is the basic unit of biogeography. It represents the spatial and temporal extent of a species' dispersal over the planet (Brown 1984; Brown *et al*. 1996). Understanding the spatial and temporal limits of the distribution of species is therefore crucial for biodiversity assessments, identification of threatened species, determining the role of each species in the ecosystem (Staley and Gosink 1999), identifying the factors limiting the distribution of species and for measuring the responses of species to environmental gradients (Keitt *et al.* 2002). At its simplest, the geographic distribution of a species is the areas in which its individuals occur (Gaston 1991). However, the factors responsible for that distribution are complex and inevitably scale-dependent (Rapoport 1982; Brown *et al.* 1996; Gaston 2003).

Scale-dependence of the factors influencing the distribution of species is well documented. For example, patterns of the habitat preference of the Eurasian eagle owl *Bubo bubo* in east Spain at three different spatial scales: nest site (7 km^2), home range (25 km^2) and landscape (100 km^2) revealed different results depending on scale (Martinez *et al.* 2003). At the nest site scale, the distribution of occupied cliffs was positively correlated with rugged terrain with a larger amount of forest cover, and negatively correlated with the nearest paved roads. However, at both the home range scale and the landscape scale, the distribution of eagle owls was positively correlated with high percentages of Mediterranean scrubland, which are the preferred habitat of European rabbits *Oryctolagus cuniculus*, the main prey of the owls (Martinez *et al.* 2003). Similarly, McAlpine *et al.* (2008) predicted koala occurrences at different spatial scales in three different states in coastal eastern Australia: Noosa in south-east Queensland, Port Stephens on the central coast of New South Wales and Ballarat in central western Victoria. They considered habitat variables at four spatial scales: the individual tree, the stand (< 1 ha), the patch (1–100 ha) and the landscape (100–1000 ha). In Ballarat, patch size had a strong, positive influence on the occurrences of koala. The number of tree species also had a strong, positive influence, while the tree basal area and the

interaction term both indicated weak, positive influences (McAlpine *et al.* 2008). At the stand scale, soil substrates and the percentage of primary tree species revealed a strong, positive influence. The distance-weighted habitat metric had a strong, positive influence, while the percentage of highly suitable habitat and road density indicated a weak, positive influence (McAlpine *et al.* 2008). For Port Stephens, patch size had a strong, positive influence, while the distance-weighted habitat metric and road density both had moderate, robustly negative influences on the occurrences of koala. The proportion of highly suitable habitat had a weaker positive effect. In addition, the number of tree species and the percentage of primary tree species at the stand scale had a moderate, positive influence, while the tree basal area and the interaction term had weak, positive influences on the occurrences of koala. At the stand scale, the occurrences of koala were negatively influenced by soil substrates. For Noosa, the distance-weighted habitat metric had the strongest influence on the occurrence of koala, while the percentage of highly suitable habitat also had a strong, positive influence (McAlpine *et al.* 2008). Tree basal areas, tree species, and their interaction terms also had a strong positive influence on the probability of koala occurrences (McAlpine *et al.* 2008). Thus, small-scale environmental variables (i.e., habitat level) may have only local influences on the distribution of species, but could have a cumulative influence on a larger scale (i.e., vegetation biome level) (Dunning *et al.* 1992).

Measurements and analyses of the influence of environmental variables on the distribution of species are normally performed using distribution maps. Species distribution maps are often utilised as the basic unit of analysis, especially when large-scale distributional information is needed and more detailed information on the occurrence of a species is scarce. These distribution maps are widely used by conservation biologists to assess the status of a species, to draw up species red lists or to identify areas of particular biological value (Cowley *et al.* 2000). Different studies have quantified the geographic distribution of species in different ways, namely, the extent of occurrence and the area of occupancy. The first is more efficient in estimates of large- scale species distribution ranges while the latter is used for small-scale estimates of species distribution ranges (Hurlbert and White 2007). The simplest way to quantify the geographic distribution of a species is by the extent of occurrence method (the location of the limits of a species occurrence) which involves the summation of the areas of

the regions in which the species has been recorded (Gaston 1991). For example, Spitzer and Lěps (1989) divided species of European noctuid moths into six distributional range groupings, starting from the largest scale to the smallest; Cosmopolitan, Palaearctic and Paleotropical, Holarctic, Palaearctic, Eurosiberian and European. However, this is a crude measure of a species' extent of occurrence and can be developed by using additional information on the regions in which the occurrence of the species has been validated by means of point locality records (Gaston 1991). The extent of occurrence is often measured in terms of the latitudinal or longitudinal extent of the locality records of a species (Reaka 1980; Stevens 1989; Dennis and Shreeve 1991). For example, Reaka (1980) quantified the geographic distribution of a species in terms of the number of degrees of latitude and longitude over which the species had been recorded. In addition, the extent of occurrence of a species can also be measured in terms of the size of the smallest area enclosed within an imaginary boundary line which encloses all of the species' locality records (Anderson 1977, 1984a, 1985; Glazier 1980). This is the case in the majority of some older field guides and many taxonomic works that illustrate species distribution as solid blocks of occurrence, and the location of the boundary line can be decided by means of a variety of criteria; although it is usually fitted by eye (Gaston *et al.*1991).

An alternative to the extent of occurrence is the use of area of occupancy (numbers of occupied quadrats) to measure species distribution. The area of occupancy measures species' extent of occurrence and includes only areas which are actually occupied by that species, where the occurrence of that species has been validated by point locality records (i.e., excluding areas for which locality records are not documented) (Gaston *et al.*1991). For example, Ford (1990) quantified the distribution range of Australian landbirds in three ways: 1) total range, measured as the number of one degree squares in which the species of landbird was recorded; 2) breeding range, measured as the number of one degree squares in which the species was recorded while breeding; and 3) the local range, measured as the number of 10 minute squares in which the species was recorded. Species range maps are typically constructed by drawing a smoothed outline around the occurrence records of species, producing an irregular, contiguous surface that ignores much of the internal structure (Brown and Lomolino 1998). Therefore, many species distribution ranges contain unoccupied gaps

within them. Rapoport (1982) stated that the range of a species is often patchily inhabited, resembling “a slice of Swiss cheese”.

Nevertheless, the defined location of a range boundary and the identified gaps within it depend upon the spatial and temporal scale over which the distribution range is mapped as well as on sampling intensity/success (Hurlbert and White 2005). For example, the distribution range of a species based on the area of occupancy will change from being coarse to being a refined measure as the mapping scale becomes smaller (Gaston 1991). At the same time, these measures are most likely to differ gradually from measures of actual extent of occurrence to become measures of areas of home range or even individual occurrence records of a species (Gaston 1991).

It is difficult to separate these two ways of measuring the distributions of species (i.e., the extent of occurrence and the area of occupancy) in practice because it is difficult to assess whether the two approaches are independent (Gaston 1991). A species with a relatively large area of occupancy may have a small range boundary when it occupies numerous sites that are restricted and spanned over a small geographical extent (Hurlbert and White 2007). Conversely, a species might have a large range boundary and yet a small area of occupancy (as measured by the total number of sites or quadrats it occupies), if those sites where it occurs are small but dispersed over a large geographic area (Hurlbert and White 2007). Although a single environmental variable could have a profound influence on the extent of occurrence of a species, the overall pattern of the distribution of a species depends on contributions of various relatively independent environmental variables (Brown 1984). For example, the distribution of Iberian lynx *Lyniix pardinus* in south-west Portugal was positively correlated with the abundance of rabbits and the presence of tall Mediterranean maquis (a shrubland biome in the Mediterranean region), but negatively correlated with road density and the amount of developed land (Palma *et al.* 1999).

Many hypotheses have been proposed to explain the relationship between the distribution of a species and environmental variables. One such hypothesis is the ecological niche-based characteristics of species which have been used to describe patterns of distribution and

abundance from local habitats to the scale of geographical ranges (Hurlbert and White 2007). However, ecological niche has been defined in different ways and for different purposes, for example, by Grinnell 1917; Hutchinson 1957, 1959; Whittaker *et al.* 1973; Schoener 1989; Colwell 1992; Leibold 1995. One such definition described the ecological niche of a species as the combination of ecological settings within which a species is capable of maintaining populations without immigration (Grinnell 1917). However, Hutchinson (1959) provided a distinction between two closely linked, although potentially discrete types of ecological niches; the fundamental and the realised niche. The fundamental niche corresponds to the range of theoretical possibilities regarding the environmental requirements of species (Hutchinson 1959). It is the area of available resources for species consumption, where its reproduction exceeds or equals one offspring in the absence of competitors or predators (Hutchinson 1957). On the other hand, the realised niche is closely related to a more limited area of a multivariate space (fundamental niches) obtained after accounting for biotic interactions (Hutchinson 1957). However, a realised niche is not a distinctive unit compared to a fundamental niche as it is reliant upon a community or assemblage composition (Flather and Hoekstra 1985). Shifts in the realised niche are expected to reflect changes in the composition of a community or an assemblage (Flather and Hoekstra 1985). Therefore, the fundamental ecological niche of a species must be a key determinant of its distribution patterns as it represents the multidimensional requirements of a species (MacArthur 1972). Biotic data (e.g., species interactions, limitations to dispersal, etc.) and historical factors are not always readily available when modelling the distribution of a species. This is problematical because absence of such data might produce overestimated geographical distributions (Araújo and Guisan 2006). Therefore, Soberón (2007) recommended dividing niches into two main categories. The first is the Grinnellian niche, which takes into consideration the environmental surroundings in which a species can live. The Grinnellian niche is defined by non-interactive environmental variables (Soberón 2007). The second category of Soberón's 2007 division of niches is the Eltonian niche, which takes into consideration the biotic interactions. In the current study, the Grinnellian niche concept was used to model the distribution of bat species because of the paucity of data on the biotic interactions that may impact bat distributions. This may have resulted in higher probabilities of species occurrences than actually occur in nature. Further, models based on the Grinnellian

niche concept are more likely to provide sound information on factors influencing the distribution and abundance of animals compared to Hutchinsonian models (James *et al.* 1984).

Predictions of species distribution patterns depend on the ability to determine the set of conditions that comprise the fundamental niche of a species and mapping the spatial and temporal occurrence of species for an area (Kearney and Porter 2009). Several hypotheses exist concerning patterns of species distribution and abundance based on the species niche concept. For example, Brown's (1984) hypothesis states that there is a relatively smooth decline in abundance from the centre of the distribution towards all the boundaries and that there is also a positive correlation between local population density and the extent of spatial distribution among similar species. Brown's (1984) hypothesis is based on three assumptions. The first assumes that the distribution and abundance of each species is influenced by a mixture of various physical and biotic variables that are essential for the survival and reproduction of its individuals. These influential, physical, and biotic requirements characterise the multidimensional niche of each species (Brown 1984). The second assumes that some sets of environmental variables are spatially distributed independently of each other and there is a significant degree of random local differences (Brown 1984). The third assumes that closely related, ecologically similar species tend to differ in a very small number of niche dimensions (i.e. closely related species tend to have similar niches) (Brown 1984). In other words, Brown's (1984) hypothesis entails that there should be a favourable area with the highest population because of the concentration of multivariate environmental factors which closely correspond to the requirements of the species in that specific area. However, the exact structure of spatial differences in distribution and abundance are determined by the amount and type of environmental variables that formulate the niche as well as on the spatial variation of these variables (Brown 1984).

In the context of Brown's (1984) hypothesis, ecologists have attempted different approaches to elucidate the distribution of environmental variables among many separate units such as individual species, species assemblages or larger geographic regions (Ford 1990; Walker and Cocks 1991; Skov 2000; Peterson 2001). For example, (Skov 2000) predicted the potential

distribution of the palm species *Chamaedorea pauciflora* in Ecuador, South America, by digitally overlaying occurrence records of this plant with elevation, mean annual temperature and humidity (Skov 2000). Suitable climatic conditions for *Chamaedorea pauciflora* were predicted on both sides of the Andes (Skov 2000). However, there is no single cause for the patterns of species distribution (Brown and Lomolino 1998; Walker and Cocks 1991; Whittaker *et al.* 2001). For example, annual mean precipitation, precipitation in the wettest month, annual precipitation range, and precipitation in the wettest quarter were the most important environmental variables that positively influenced the distribution of the red kangaroo *Macropus rufus* in Australia (Walker and Cocks 1991). Therefore, the observed geographical distribution of a particular species is a result of multiple variables. The relationship between species occurrence records and multiple environmental factors (Species-environment relationships) have been used to identify the limits to species distributions and species responses to environmental gradients (Keitt *et al.* 2002; Cushman and McGarigal 2004). With increased rates of extinction as a result of anthropogenic habitat loss and climate change, practical understanding of how different aspects of the environment affect distribution and abundance of species is vital (Keitt *et al.* 2002; Berry *et al.* 2004; Tognelli and Kelt 2004).

An added complication is that historical environmental changes (e.g., climatic and geological) can exert considerable influence on species distribution patterns, while current environmental variations account for maintaining these patterns (Brown 2001). Three main types of interconnected historical processes (i.e., dispersal, extinction, and speciation) have influenced the distribution of small mammals in the Philippines, Borneo, southern Mexico and western United States. For example, Pleistocene changes in climate, sea level and vegetation that have caused habitat barriers to dispersal to change periodically permitted the exchange of non-volant mammals between the Philippines, Borneo, southern Mexico and western United States (Brown 2001). Extinction decreases the diversity of species in the presence of barriers while prolonged isolation of populations in different habitats causes evolutionary changes that might lead to the formation of restricted endemic species (Brown 2001). To render the problem more tractable, ecologists have divided environmental variables influencing contemporary distribution of species into several categories.

Austin (1980) divides environmental predictors of species distribution patterns into three main categories: 1) direct predictors; 2) resource predictors; and 3) indirect predictors. Direct predictors are those that exert a direct influence on the species but are not directly exploited by the species (Austin 1980). In other words, direct predictors are measures of the availability of energy in the environment (e.g., temperature and precipitation variables (Currie 1991)). Energy accessible to vertebrates could be better characterised by atmospheric energy (Currie 1991). For example, ectotherms (cold-blooded animals) adjust their body temperature by the direct absorption of heat from their surrounding environment (Randolph 1973; Hainsworth 1981). On the other hand, the metabolic costs for homeotherms (warm-blooded animals) decline to the upper limits of the thermoneutral zone, after which they begin to rise again (Randolph 1973; Hainsworth 1981). In addition, potential evapotranspiration might be regarded as a measure of ambient energy, as it is the amount of water that evaporates from a saturated surface and it relies on the availability of energy to evaporate water as well as on the relative humidity (Currie 1991).

Indirect predictors are factors (e.g., altitude, latitude or longitude) that have no direct influence on the species or its interaction with other members of the community (Simpson 1964; Ker and Packer 1997; Rahbek and Graves 2001; Jetz and Rahbek 2002). The effect of indirect predictors on species distribution is through their influence on climatic variables such as the monthly minimum temperature or rainfall, which do have a direct influence on the species distributional limits by reducing local temperature or evapotranspiration rates (Austin 2002; Guisan and Hofer 2003).

Resource predictors are based on those factors such as water and nutrients that are consumed or assimilated by species (Guisan and Hofer 2003). The above-mentioned categories of predictors are not necessarily mutually exclusive (i.e., water could be a resource predictor under conditions of low availability and a direct predictor when it is sufficiently abundant and influences the microclimate by reducing local temperature) (Austin 2002). Austin (2002) also placed predictors of species distribution into two additional categories: proximal and distal. The most proximal predictor is the causative variable that determines the species response (Austin 2002). For example, in the case of a plant, accessible soluble soil phosphate

concentration at the root hair is more of a proximal predictor than total soil phosphorus (Austin 2002). In this context, indirect predictors are clearly distal variables, for example, altitude, latitude or longitude (Austin 2002). However, most biogeographical studies ignore these categories; instead, they pay particular attention to the physical and climatic aspects of species distributional patterns and try to identify specific environmental correlates of distributional range limits (e.g., Root 1988; González *et al*. 1990; Hinsley *et al.* 1995; Cowlishaw and Hacke 1997; Guisan and Hofer 2003).

For instance, there is general consensus that within cold or temperate terrestrial regions the most important environmental predictors of species distributions are related to ambient energy such as potential evapotranspiration or solar radiation (Currie and Paquin 1987; Lennon *et al*. 2000). For example, summer temperature was found to be the main predictor of the breeding distribution of 87 out of 194 (45%) terrestrial and freshwater bird species in Britain (Lennon, Greenwood and Turner 2000). Furthermore, the northern distributional limits of 148 bird species in a continent-wide study in North America were positively correlated with two temperature variables: the average minimum January temperature and the mean length of a frost-free period (Root 1988). On the other hand, the breeding distribution of the Spanish Imperial Eagle *Aquila adalberti* in Spain was positively correlated with an annual mean temperature range (mean temperature of the hottest month – mean temperature of the coldest month) and higher summer temperatures (González *et al*. 1990). Similarly, distributional limits of reptile species with a restricted range in Switzerland were explained by average July temperatures (Guisan and Hofer 2003), whereas the mean summer and winter temperatures were negatively correlated with the distribution of the Iberian desman *Galemys pyrenaicus* in Spain (Morueta-Holme *et al.* 2010).

Other climatic variables such as precipitation have also been documented as having an influence on the distribution of species. For example, the eastern distributional limits of 148 bird species in North America were positively correlated with a mean annual precipitation (Root 1988). On the other hand, the breeding distribution of *A. adalberti* in Spain was positively correlated with higher rainfall in spring, summer and winter (González *et al*. 1990),

whereas the distribution of primate species in continental Africa was positively influenced by the seasonality of rainfall in both directions from the equator (Cowlishaw and Hacke 1997).

Non-climatic factors such as vegetation type and structure have also been found to influence the distribution of species. For example, the northern and eastern distribution limits of 148 bird species in North America were positively correlated with simulated vegetation (Root 1988). In addition, the type of vegetation constituted the most important variable influencing nest-site locations of the sage grouse *Centrocercus urophasianus* in southern Oregon, USA. Bitterbrush *Purshia tridentata* shrubs within the vegetation class were positively correlated with nest-site locations of *C. urophasianus* (Yost *et al*. 2008). On the other hand, riparian vegetation and Wyoming big sagebrush *Artemesia tridentata wyomingensis* were negatively correlated with the nest-site location of *C. urophasianus* (Yost *et al*. 2008). However, habitat-related variables explained only a small proportion of the distribution of the European wildcat *Felis silvestris* in Southern Portugal (Monterroso *et al.* 2009), whereas the breeding distribution of *A. adalberti* in Spain was positively correlated with land use types such as less cultivated land and irrigated farmland (González *et al*. 1990). Factors on a larger scale can also impact the distributions of animals. For example, the breeding distributions of 31 bird species in eastern England were influenced by factors associated with the wider landscape on a scale larger than that of their immediate habitats. The presence of breeding populations of some bird species such as the Long-tailed Tit *Aegithalos caudatus* and the Robin *Erithacus rubecula*, amongst others, was positively correlated with the length of hedgerows in the surrounding landscape (Hinsley *et al.* 1995).

Non-climatic environmental factors such as elevation can also influence bat distributions. Elevation was negatively correlated with the distribution of Peruvian bat species. Of the 101 bat species distributed along an elevation gradient, 82 species were distributed below 400 meters above sea level (m.a.s.l) and only 10 species higher than 3200 m.a.s.l (Graham 1983). In addition, the number of bat species captured along an elevation gradient decreased with decreasing altitude in eastern Mexico. A decrease of approximately eight bat species for every 1000 m.a.s.l was observed in the Queretario region of eastern Mexico (Navarrol and Leon-Paniagua 1995). Furthermore, altitude was negatively correlated with the distribution of bats

in China (Li *et al.* 2005). However, elevation is expected to have little or no influence on the distribution of bats in South Africa (i.e., most of South Africa is situated at a high elevation).

Because species are adapted to only a certain combination of environmental variables, they can occur only in a subset of their geographic range (Collins and Glenn1991) such as along a particular elevation gradient. Elevation was shown to influence the distribution of species in different ways (Heaney *et al.* 1989; Monterroso *et al.* 2009). The distributions of non-volant animals can be markedly influenced by non-climatic factors on a small scale (Patterson *et al.* 1996). The geographical distribution and abundance of non-volant small mammals (families Soricidae and Muridae) were positively correlated with elevational range in the central Philippines (Heaney *et al.* 1989). Elevation and slope were the next most important variables positively influencing the distribution of *F. silvestris* in Southern Portugal after the positive influence of the relative abundance of the wild European rabbit *Oryctolagus cuniculus* (Monterroso *et al.* 2009). Generally, species with broad niches will occur along a larger elevation gradient than species with narrow niches (Collins and Glenn1991).

In the same manner, many studies have investigated the relationship between the ecological attributes of species and their geographical distributions. Generalist species capable of exploiting a variety of food and other resources, both regionally and locally, are less prone to extinction. They use a wide range of habitats and are thus less likely to be severely influenced by environmental factors and are therefore expected to be widely distributed (Brown 1995; Letcher and Harvey 1994; Duncan *et al*. 1999). In contrast, dietary specialist species tend to be more vulnerable to unfavourable environmental factors resulting in limited distributional ranges (Bright 1993; Angermeier 1995). Furthermore, species with restricted distributions are most likely to be influenced negatively by anthropogenic environmental changes such as habitat destruction (Bright 1993; Angermeier 1995).

Bat species have emerged as model organisms for studies of the relationship between the distribution of species and the environment (Lyons and Willig 2002; Wang *et al.* 2003). Bat distributions offer key insights into macroecological patterns (i.e., relationships between organisms and their environment on large spatial scales) and the factors that drive these

patterns (Willig *et al.* 2003). This is because of: 1) the great taxonomic and ecological variety within the bat order, Chiroptera (Arita and Fenton 1997; Simmons 2003); 2) the wide distribution of bats across all continents except Antartica (Koopman 1984); and 3) the remarkable spatial differences in the abundance of bat species (Findley 1993; Stevens and Willig 1999, 2000, 2002). Chiropterans are unique elements (i.e., the only volant mammals) for comparative macroecological studies with non volant mammals and avifauna (Willig *et al.* 2003). Bats are crucial elements of many communities and are keystone species as pollinators, seed dispersers and insectivores regulating nocturnal insect populations (Mickleburgh *et al.* 2002).

Identifying factors influencing the distribution of bats presents a challenge. Thorough surveys of bat populations are difficult to conduct since bats are nocturnal animals that possess wide home ranges and their identification is problematic, especially in flight (Walsh and Harris 1996b). In addition, certain bat species could be absent from otherwise suitable habitats because some resources have a discontinuous distribution (e.g., roosts (Law, Anderson and Chidel 1999)). Therefore, a combination of species distribution and environmental correlates, based mainly on biophysical (i.e., vegetation, land use and geology) and climatic predictors, might be required for predicting the distributions of bat species (Jaberg and Guisan 2001). Hence, the correlation between the distribution and the environmental variables could be deduced in order to obtain the probability of occurrence for a species (Schall and Pianka 1978; Wolfheim 1983). In addition, specific variables can be selected from climatic and biophysical descriptors as being the most important variables that influence the distribution of a particular species (Phillips *et al.* 2006). Similar approaches have been followed recently to model different species on a regional or country-wide scale in order to identify factors influencing the distributions of non-bat species (Yost 2008): Sage grouse *Cenrocerus urophasianus* in the United States of America, (Boubli and de Lima 2009); Brown-backed bearded sakis *Chiropotes israelita* and Black uakaris *Cacajao spp.* in Western Amazon, Brazil, and (Hoenes and Bender 2010); Mule deer *Odocoileus hemionus* and Gemsbok *Oryx gazella* in New Mexico.

Despite the key role that bats play in ecosystems, only a few detailed studies have been conducted on the large-scale distributional patterns of bats (e.g., Lyons and Willig 1997 in the continental New World, Yom-Tov and Kadmon 1998 in Israel; Wang *et al*. 2003 in Mexico; Lamb *et al*. 2008, in Africa; Monadjem *et al.* 2010, in Southern and Central Africa; and Rebello *et al.* 2010, in Europe). However, different environmental factors have been found to influence bat distributions.

Temperature variables were the main determinants of bat distribution patterns in China. These patterns were positively correlated with annual average temperature, day of temperatures above zero degrees Celsius, January average temperature, and July average temperature (Li *et al.* 2005). In addition, temperature was among the potential limiting factors for the distribution of bats in Mexico. Although Wang *et al.* (2003) did not use quantitative measures for temperature, more bat species were associated with hot temperatures (22-26°C) (24 species) than with moderate (14-18°C) (18 species), very hot (26-32°C) (13 species) or warm (18-20°C) (8 species) conditions. Likewise, temperature has been considered a limiting factor in the distribution of insectivorous bats in Israel (Yom-Tov and Kadmon 1998). Three desert species, *Barbastella leucomelas* (Family Vespertilionidae), *Nycteris thebaica* (Family Nycteridae) and *Taphozous perforatus* (Family Emballonuridae) were found only alongside the Rift Valley (i.e., the warmest region of Israel (Yom-Tov and Kadmon 1998)). It appears that desert bats in Israel demonstrate a strong affinity for the warmest region where the mean August (the hottest month) temperature is 30°C and the mean annual precipitation is lower than 300 mm (Yom-Tov and Kadmon 1998). Furthermore, the distribution of bats (both insectivores and frugivores) in southern Africa were predicted to be strongly correlated with temperature seasonality (r=0.707) and to a lesser extent with minimum monthly temperature (r= 0.70) (Andrews and O'Brien 2002).

Precipitation variables have also been found to influence the distribution of bats. Bat species were clustered as follows, based on the means and variances of precipitation at points of occurrence in Israel: desert species (166.8mm and 42.02mm); Mediterranean species (605.3mm and 49.06mm); and widespread species (418.7mm and 63.50mm) where the means of all the clusters were significantly different from each other ($P<0.01$) (Yom-Tov and

Kadmon 1998). Annual rainfall was among the main determinants of bat distribution patterns in China. Local abundance of bat species in China was determined by availability of food which is usually related to rainfall (Li *et al.* 2005). Precipitation was a potential limiting factor for the distribution of bats in Mexico. Regions of medium precipitation (800-1200mm) levels were positively associated with most bat species in Mexico (Wang *et al.* 2003). In arid regions, as in parts of South Africa, it has been noted that there is a positive correlation between high rainfall and the distribution patterns of South African mammals on a latitudinal basis, including bats (Nel 1975). In addition, the distribution of large mammals (90-360kg) in Southern Africa were predicted to be less correlated with maximum monthly precipitation (r=0.468) and not at all with annual rainfall (r=0.287) (Andrews and O'Brien 2002). In contrast, the distributions of small mammals (0-1kg) were predicted as being highly correlated with both maximum monthly precipitation (r=0.72) and annual rainfall (r=0.587) (Andrews and O'Brien 2002).

Vegetation types have also been shown to influence the distribution of bats. Vegetation was a potential limiting factor for the distribution of bats in Mexico. Bat species associated with hot temperatures (22-26°C) tend to be linked with tropical vegetation types (e.g., tropical deciduous forest) (Wang *et al.* 2003). In contrast, bat species associated with moderate temperatures (14-18°C) were linked to temperate vegetation types (e.g., pine–oak forest and scrubland) (Wang *et al.* 2003). However, vegetation types did not distinctly influence species distribution of Chiroptera in China (Li *et al.* 2005). Although bats show less habitat specificity than other South African mammalian orders, they are mostly associated with particular habitats such as woody vegetation types (Gelderblom 1995). The distribution of bats (both insectivores and frugivores) in southern Africa, including South Africa**,** were predicted to be positively correlated with woody plant species (r =0.882) (Andrews and O'Brien 2002). However, there are some conflicting results concerning factors related to habitat heterogeneity not influencing bat species distribution in South Africa. For instance, increased habitat complexity has no significant effect on bat faunas in the Kruger National Park (Rautenbach *et al.* 1996). This could be attributed to the small-scale nature of their study. They suggested that the situation in Africa may be different in areas where woodlands are restricted to river valleys. In such situations, the relationship between habitat

heterogeneity and bat distribution could be driven by factors such as availability of roost structures (Humphrey 1975; Li *et al.* 2005) and cover for predator avoidance (Rydell and Speakman 1995) in the more complex habitats.

Besides climatic and biophysical factors, some ecological factors related to bat species have also influenced their distribution. Studies in Mexico confirmed a significant relationship between species distribution and feeding habits of bat species using four feeding categories: aerial insectivores, gleaners, frugivores and nectarivores. Gleaners, including carnivores and insectivores, have restricted distributions in Mexico, while aerial insectivores tended to have wide distributional ranges (Arita *et al*. 1997). Gleaners that fly slowly and manoeuvre among vegetation (Norberg and Rayner 1987) are most likely to be influenced negatively by human-induced changes on vegetation or other land use/land cover changes. Specialisation can also lead to increased reliance on one aspect of the habitat, for example, caves for roosts. In the United States of America, all five species of bats listed as being endangered by the IUCN used caves as roost sites for at least part of the year (McCracken 1989). Furthermore, the endangered Kitti's hog-nosed bat *Craseonycteris thonglongyai* (IUCN 2006), confined to two small areas of South-east Asia, relies entirely on caves for day roosting (Humphrey and Bain 1990; Bates *et al.* 2001; Huston *et al.* 2001). In addition, bats in the genus *Rhinolophus* have been found to be influenced negatively by habitat fragmentation in Britain (Bright 1993). This is due to the morphological limitations of their wings that make rhinolophids clutter habitat specialists (Norberg and Rayner 1987).

Many studies have aimed to find correlates of species distributions. Most of these that have attempted to identify the potential factors that correlate with species distributional limits have involved the use of modelling approaches. Such attempts were based on using statistical approaches that highlight the distribution of variables among many separate units such as individual species, species assemblages or larger geographic regions (Brown 1981). The development of statistical approaches that tried to correlate locality records or the abundance of species to environmental variables started as early as the beginning of the twentieth century. Among those was Johnston (1924) who predicted the range expansion of an invasive cactus species in Australia. He correlated climate variables with observed distributions of the

prickly pear cactus *Opuntia fuliginosa* to predict the spread of this species in Australia. However, the earliest improvements in computer-based extrapolative modelling of the distribution of species appear to have originated in the mid-1970s. This improvement was inspired by the various measurements of species–environment relationships available at that time (Austin 1971). The earliest computer-based species distribution modelling attempt appears to be the niche-based spatial predictions of crop species by Henry Nix and collaborators in Australia (Nix *et al*. 1977). Niche-based or habitat-suitability modelling techniques utilise information provided by species occurrence records and their associated environmental variables to produce statistical functions that predict the occurrence of a potentially suitable habitat for a species (Guisan and Zimmerman 2000). These statistical functions can then be used to extrapolate the distribution of a species to areas where environmental variables are known to be suitable but for which locality records for the species are not yet available. This allows for a cost-effective means to map species distributions in large areas and at small spatial resolutions (Hausser 1995; Guisan and Zimmerman 2000; Peterson *et al*. 2002) hence, reducing the necessity for large scale ground-truthing of species distributions within unsuitable areas of their distributional range (Gaston and Williams 1993).

Recently, the technological advancement of geographical information systems (GIS) and high quality digital maps of various climatic and biophysical variables have assisted ecologists and other natural scientists in studying these species-environment relationships. The availability of GIS information and digital maps resulted in the development of techniques for quantitative mapping of species distributions. This has resulted in several methods that are used in species distribution modelling (SDMs).

Generally, two SDM approaches are used: correlative (pattern-to-process) and deductive (mechanism-to-pattern) (Corsi *et al*. 2000; Diniz-Filho *et al.* 2010). The correlative approach is used to predict the ecological requirements of the species from the occurrence records of that species. In this approach, the habitat requirements of a species are observed and subsequently the characteristics of that habitat are extrapolated to wider areas (Skidmore 2002). The correlative approach of SDMs provides baseline information on the fundamental

niche of a species (Peterson *et al*. 1999; Peterson 2001; Peterson and Holt 2003). It relates limits on species occurrence records to sets of environmental conditions at those species occurrence localities (Wiens *et al.* 2009). These correlative SDMs are increasingly being applied to predict the impact of future land use or climate change on animal distributions (Austin *et al*. 1996; Peterson *et al*. 2002; Thuiller 2003a), or to develop ecological networks for species conservation on large spatial scales (Bani *et al*. 2002). Correlative SDMs have also been used recently to investigate environmental factors that influence the current distribution of species (e.g., Yost *et al.* 2008; Monterroso *et al.* 2009; Morueta-Holme *et al.* 2010). However, correlative SDMs do not provide comprehensive information on factors influencing species distributions because they mostly do not take biotic interactions into consideration (Kearney and Porter 2004). Such biotic interactions (e.g., interspecific competition and predation) might limit the ability of species to respond appropriately to climatic conditions through space as well as adapting to a new habitat (Guisan and Thuiller 2005). The exclusion of biotic interactions from correlative models might decrease the performance of these models (Gutiérrez *et al*. 2005). However, Pearson and Dawson (2003) suggested that biotic interactions might be insignificant in influencing species distributions at larger scales (i.e., regional to continental), where climate is most likely to have a significant influence on species distributions. Most biotic interactions are however, local and individual specific, which could cause potential challenges for all SDMs (Kearney and Porter 2009).

The deductive or mechanistic approach, on the other hand, utilises the ecological characteristics of a species to predict suitable areas from environmental variables (i.e., variables that are known or suspected to influence the distribution of a species) (Varghese *et al.* 2010; McNay *et al.* 2011). Thus, the definite location of species occurrence in an area does not have to be identified. Instead, existing detailed knowledge of the species ecology and life history traits can be utilised to derive modelling rules (Tobalske and Tobalske 1999). These rules are developed through a process of aggregation and simplification of information from published literature or expert opinions (Ottaviani *et al.* 2004).

The correlative rather than the deductive or mechanistic model approach was chosen for the purpose of this study because previous studies suggest that biotic interactions may have a

relatively minor influence on South African bat assemblages (Schoeman and Jacobs 2008; 2011). Instead, abiotic factors such as competition may exert a greater influence on bat assemblages than biotic interactions (Schoeman and Jacobs 2011).

If so, abiotic factors might also play a major role in determining patterns of bat species distribution in South Africa. Although data on the distribution of South African bats is generally good (e.g., see Taylor 2000; Monadjem *et al.* 2010), factors influencing the current distribution of bats in South Africa are not well known. The current study will use SDMs to predict the distribution patterns (e.g., Elith and Leathwick 2009) of bats across South Africa with the aim of identifying the abiotic factors limiting their distribution.

Several methods exist to create distribution maps for species from SDMs. A main difference among them is the quality of data required (Brotons *et al.* 2004). These SDMs are classified into two main groups; presence-absence models and presence-only models. Presence-absence models include, for example, generalised linear models (GLM), generalised additive models (GAM), classification and regression tree analyses and artificial neural networks (ANN). These types of methods entail good quality presence and absence data to create statistical functions that calculate distributions of the presence or absence of a species (Manel *et al*. 1999; Guisan and Zimmerman 2000).

On the other hand, presence-only models include, for example, the Ecological Niche Factor Analysis (ENFA), Bioclim, Domain, Mahalanobis distance (MD), Garp and recently Maximum Entropy modelling (MaxEnt). The presence-only models use only confirmed locality records where species absence data are poorly confirmed or unavailable (Carpenter *et al*. 1993; Hirzel *et al.* 2002a; Farber and Kadmon 2003). The presence-only models depend on the identification of environmental variables at locations where species occur, which are subsequently compared to the environmental variables of background points (i.e., localities with similar enviromental variables for which there are no locality records) (Stockwell and Peterson 2002a; Hirzel *et al.* 2002a). Data quality is most likely to be the main factor determining the choice and reliability of all model predictions (Zaniewski *et al*. 2002; Stockwell and Peterson 2002a, b). Therefore, thorough knowledge of the predictive accuracy

of models and their area of application is necessary especially in the early stages of the development of projects aimed at mapping species distributions (Brotons *et al.* 2004).

There have been some concerns about the data and methods of establishing model validity used in species distribution models. For example, some problems that stem from the data used in statistical models can occur. These problems include the proper scale of observations and accuracy of locality records especially when using ecological field data with GIS and species locality records (Pitt *et al.* 1997; Franklin *et al*. 2000). The sources of these problems mostly originate from the method of data acquisition in the field which could suffer from subjectivity as well as low spatial and temporal coverage (Pitt *et al.* 1997). Such problems could make decisions about which statistical models to use difficult during data analysis (Pitt *et al.* 1997). Problems could also occur with regards to statistical models concerning the supposed error function (Austin 2002), that is, the measurement error (Altman *et al*. 2007); choice of model, that is, the generalised linear model (GLM), the generalised additive model (GAM) or the classification and regression tree (CART) (Breiman *et al*. (1984)) and model validation methods. Some decisions by the modeller can have significant effects on the model outcomes. For example, statistical decisions can alter the ecological model itself as well as the choice of data transformation. For example, log transformation to even out the variance will modify the functional relationship from an additive to a multiplicative form (Austin 2002). Another significant concern is the complexity of assessing the non-use of a resource by an animal as well as estimating the absence of a mobile or cryptic animal from a habitat, which may affect the performance of the statistical model (Austin 2002). In addition, many ecological theories have been neglected in the process of modelling the distribution of a species. This is evident in the species distribution studies based on statistical models that are static and contain no dynamic elements (Guisan and Zimmermann 2000; Guisan and Theurillat 2000). In the static models, the assumption is that an organism is in equilibrium with the environment, or at least in quasiequilibrium, where the rate of change is slow relative to the life span of the organism (Austin 2002). Another concern regarding the statistical models is that they are predicated only on the realized niche of a species but almost ignore the fundamental niche (Austin and Smith 1989; Austin 1992; Malanson *et al.* 1992; Franklin 1995; Guisan and Zimmermann 2000). As models of the distribution of a species generally

concentrate on environmental predictors, other processes such as dispersal, competition, succession, fire and grazing pressure are not usually integrated (Austin 2002). Most of the statistical models of distribution have neglected to incorporate the reproductive success of a species in the modelling process (Heegaard 2001). Also, the boundary between spatial autocorrelation methods and ecological processes requires special attention when modelling the distribution of a species (Guisan *et al.* 2002). In addition, another potential problem is that many models do not differentiate between types of environmental gradients or predictors, for example, direct predictors such as temperature and precipitation variables: resource predictors such as water and nutrients; and indirect predictors such as altitude, latitude or longitude (see Austin 1980; ter Braak 1985, 1986; Austin and Smith 1989; Guisan and Zimmermann 2000). Therefore, it is important to differentiate between types of gradients or predictors as species are expected to respond differently to different types of gradients (Huston 1994). This renders a comparative analysis of species' response to different gradients difficult because gradients are not equivalent (Austin 1999).

Although models based on both indirect and direct predictors will be the most robust and broadly applicable compared to models based on only one type of predictor, they are the least practical regarding accurate knowledge of what to measure or availability of resources and time to measure them (Austin 2002). For example, modelling species distributions by using only indirect variables (e.g., altitude) will have only local value for prediction or understanding species' ecological requirements. However, modelling the correlates of various environmental variables and the presence of bat species is crucial for the conservation management of these species (Greaves *et al.* 2006).

Bats represent 20 percent of mammalian diversity worldwide (Schipper *et al.* 2008). They are vulnerable and prone to extinction because of their low reproductive rates (most produce only one pup per year), habitat loss and persecution from humans (Mickleburgh *et al*. 2002). Approximately 25 percent of bat species are of conservation concern, with an additional 21 percent being classified as near threatened (Mickleburgh *et al*. 2002). Their conservation status has received increasing attention at an international level reflecting the importance of their role in biodiversity and ecosystems (Huston, Mickleburgh and Racey 2001). There is an

increasing agreement that further efforts are required to ensure the survival of bat species globally and this will depend on our basic knowledge of the species (Furman and Özgül 2004). Therefore, determining the environmental factors influencing their distribution patterns is important in making knowledgeable conservation decisions.

The chiropterans within South Africa's border are even more susceptible to threats than those at the global scale. A total of 74 species of bats exist in Southern Africa (Taylor 2000). Chiropterans represent about 22 percent of the total number of mammalian species found in southern Africa. Approximately 56 percent of bat species in South Africa were assigned one of the threat categories of the International Union for the Conservation of Nature (IUCN) Red List for the mammals of South Africa (Friedman and Daly 2004). Of the 57 species of bats found within South Africa's border, 50 of them were considered as being resident by the IUCN Red List for the mammals of South Africa and 7 species were considered vagrant (Friedman and Daly 2004). The 50 bat species considered for the IUCN assessment belong to 8 families, Vespertilionidae (22 species), Rhinolophidae (10 species), Molossidae (7 species), Nycteridae (3 species), Pteropodidae (3 species), Hipposideridae (2 species), Miniopteridae (2 species) and Embalonuridae (1 species). Two species of bats (4%) were identified as being critically endangered, 2 (4%) endangered, 6 (12%) vulnerable, 18 (36%) near threatened, 19 (38%), of least concern, and 3 (6%) were considered as being data deficient (Friedman and Daly 2004) (see Appendix 5 for further details).

Although the fine-scale distributional data for bats in South Africa is generally good (e.g., Rautenbach *et al.* 1996; Jacobs 1999; Aspetsberger *et al.* 2003; Jacobs *et al*. 2006; Jacobs *et al.* 2007b; Schoeman and Jacobs 2008), there is a conspicuous gap in our knowledge of the large scale environmental factors influencing bat distributions in South Africa. The evidence for the influence of biotic factors on bat community structures in South Africa is ambiguous (see Schoeman and Jacobs 2008; 2011, and the references cited therein).

Identifying environmental factors influencing the current distribution of bats in South Africa is important as these factors could be used to extrapolate from the distribution of bats to other mammals and birds. In addition, it is most likely that the distribution patterns of bat species

in South Africa would be analogous to the species distribution patterns of other mammals and birds. With a marked east-west aridity gradient in South Africa (Schulze 1997*a*; O'Brien 1993, 1998; O'Brien *et al.* 1998), it has also been noted that most mammalian taxa in South Africa are distributed towards the east (Nel 1975). Furthermore, variation in bird species distribution patterns in South Africa is mostly associated with the apparent east-west moisture gradient as a result of rainfall variability. The distribution patterns of birds in South Africa are also related to primary productivity and vegetation heterogeneity (van Rensburg *et al.* 2002). The distributions of most species of bats in South Africa should be concentrated in the wet east rather than in the dry west of South Africa.

Here, the aims were to determine the factors limiting the distribution of bats and to generate probability of occurrence maps for bats in South Africa. There appeared to be little known about bat distributions in the Northern Cape Province so an attempt was made to remedy that by surveying bats in this region of South Africa. Bat locality data from the Northern Cape were combined with that taken from the literature for the rest of South Africa, and then correlated them with environmental variables at those known localities to determine which variables exerted the greatest influence on the distribution of individual species. The correlation between the known locality records for bats and the environmental variables at those localities was used to obtain the predicted distributions (probability of occurrence maps) based on the similarity of environmental variables elsewhere in South Africa with those at known localities for bats. To the researcher's knowledge, this study is the first of its kind that attempted to correlate environmental variables with a countrywide scale distribution of bats in South Africa. The only study related to this one is that of Monadjem *et al.* (2010) who modelled the distribution patterns of bats in Southern and Central Africa using MaxEnt. However, the author's intention was to show only the probability of occurrences without investigating the factors responsible for the current distribution patterns of bats in their study area.

Given the number of well-documented species (37 species), this undertaking had to be made more tractable by limiting the current study to a single country in a warm temperate region in the southern hemisphere, viz., South Africa. Undertaking such a study in a warm temperate

region in the southern hemisphere was essential since little is known about the factors that influence bat distributions, or indeed that of other animals in this part of the world. Several hypotheses were therefore tested regarding the factors that influence the distribution of individual bat species in South Africa.

Firstly, it was hypothesised that environmental variables relating to primary productivity, especially precipitation variables (i.e., rainfall), are expected to influence bat species distribution in South Africa given the marked east-west precipitation gradient in this country. Precipitation is strongly related to the productivity hypothesis, which proposes that greater diversity of producers result in greater primary production, all else being constant (Pianka 1966). As it is impractical to keep everything else constant, the productivity hypothesis can be tested only indirectly or in rudimentary ways. Therefore, precipitation may be used as a proxy for productivity (Pianka 1966). Secondly, it was hypothesised that environmental variables relating to ambient energy (temperature variables), especially extreme temperatures, influence the distribution of bats in South Africa. He suspected that temperature would play a role in determining bat distributions in South Africa due to its effect on the thermoregulatory capabilities of bats (e.g., Reeder and Cowles 1951; Bronner *et al.* 1999; Jacobs *et al.* 2007b). Thirdly, it was hypothesised that roost availability was likely to limit the distributions of cave/crevice roosting bats or bats that use human-made structures in South Africa. Studies have shown that the distribution of most bat species listed as endangered by the IUCN are likely to be limited by roost sites (McCracken 1989; Humphrey and Bain 1990; Bates *et al.* 2001; Huston *et al.* 2001). In this study, roost availability will be determined via environmental factors relating to biophysical variables such as geology (distribution of potential cave roosts) and land use/land cover (distribution of potential roosts in human structures). Lastly, it was hypothesised that environmental variables relating to the habitat types (i.e., biomes as surrogates for vegetation types) are expected to influence bat species distribution in South Africa. Most bat species should be limited by the extent of vertically complex habitats such as Savanna and forest biomes rather than by biomes like fynbos that are not vertically complex (e.g., Bazzaz 1975). Vegetation types have been found to influence the distribution of mammals in South Africa. Several authors noted high mammalian species diversity in savannas and suggested that it could be a result of the high diversity of habitats

(Rautenbach 1978; Siegfried and Brown 1992).

The following predictions associated with the hypotheses were tested. The primary productivity hypothesis proposes that precipitation would be the most important factor limiting the distribution of bats whose South African distributions are centered in the wet eastern region. Under the ambient energy hypothesis, it was proposed that temperature variables, especially extreme measures of temperature such as means of the coldest or warmest months or quarters, would have a weak influence on bat species distribution in South Africa. This is because most of the Southern African region has a subtropical to warm temperate climate (O'Brien 1993; Andrews and O'Brien 2000) and temperature ranges are relatively lower in South Africa than in the temperate regions of the Northern Hemisphere. For example, average temperatures are about 7^{o}C and 11^{o}C in winter and summer respectively in the Graaff-Reinet area within inland South Africa (van der Merwe *et al.* 1994), compared to average temperatures of about -16.4^{o}C in winter and 15.8^{o}C in summer recorded in Edmonton in Alberta, Canada (Phillips 1990). Under the roost availability hypothesis, the predictions were as follows: 1) the distribution of cave or fissure roosting bats are likely to be limited by geological elements that provide such roosts. Geological formations that might contain limestone (cave-forming rocks) and other geology-related roost structures such as crevices are expected to positively influence the species distribution of cave-dwelling bats; 2) land use/land cover type that add structural components to the landscape (e.g., residential buildings) are expected to positively influence the distribution of bats that use human structures as roosting sites in South Africa (e.g., the Egyptian free-tailed bat *Tadarida aegyptiaca* and the Cape serotine *Neoromicia capensis*). Roost specialisation would explain the distribution patterns of South African bats more than other ecological and life-history attributes. This is indicated by the fact that the most widely distributed bat species in South Africa; the Natal long-fingered bat *Miniopterus natalensis*, Geoffrey's horseshoe bat *Rinolophus clivosus*, *Tadarida aegyptiaca*, and *Neoromicia capensis*, belong to different families but are all roost generalists having flexible roosting habits utilising a variety of roost structures (Schoeman 2006). However, roosting requirements alone cannot explain why species, for example, *Chaerephon pumilus* that use human structures as roosts, nevertheless have a restricted distribution in South Africa (Taylor 2000). In these cases other life-history or

ecological characteristics may offer better explanations for their distributions. Under the habitat heterogeneity hypothesis, it was predicted that habitats that are horizontally heterogeneous and vertically complex, for example, Savanna and Forest biomes (which consist of large woody vegetation), are expected to limit the distributions of more species than habitats that are horizontally heterogeneous but vertically less complex (e.g., the fynbos biome). Large trees might be considered "keystone structures" (Tews *et al*. 2004) providing resources (i.e., fruit as food) and shelter in the form of roosting sites (for tree roosting species) which are crucial for the survival of bat species, especially frugivorous bats, for example, *Epomophorus wahlbergi*. The last prediction was that phylogeny or the taxonomic position of the species is expected to have no influence on the distributional patterns of bats in South Africa. Some bat species in South Africa belonging to different families indicate similar patterns of distribution. For example, the Cape serotine *Neoromicia capensis* (Family Vespertilionidae) and the Egyptian free-tailed bat *Tadarida aegyptiaca* (Family Molossidae) are both widely distributed in South Africa and sympatric over most of their ranges, but belong to different families.

The above predictions were investigated by using MaxEnt to model the distributions of 37 species of South African bats using locality records from museums covering the entire country and combined with the researcher's own data for the Northern Cape Province.

Chapter 2

MATERIALS AND METHODS

2.1 Study Area

This study covers South Africa excluding Lesotho and Swaziland. The Republic of South Africa is located at the southern tip of the African continent. It extends almost from the 22^{o} to the 35^{o} southern latitude with an overall surface area of 1,221,040 square kilometres. South Africa's varied coastline stretches for 2,954 kilometres from the Orange River mouth on the Namibian border in the west to Ponto do Ouro on the border of Mozambique in the east (vander Merwe *et al.* 1994). The country consists of three main geographical regions, namely, a great interior plateau, an escarpment of mountain ranges that rims the plateau on the east, south and west as well as a coastal belt lying between the escarpment and the sea. Most of the plateau consists of highveld that is rolling grassland, situated at 1,220–1,830 m above sea level (asl). The southern mountains are over 2,000 m (asl), while the eastern ones reach a height of over 3,000 m (asl) (Bothma and du Toit 2010). In addition, in the northeast of the plateau are the Bushveld Basin (a zone of savannah situated at 610–910 m (asl)) and the Limpopo River basin (van der Merwe *et al.* 1994).

South Africa is characterised by three distinct rainfall regions: the summer, the winter and the all-season regions. The summer rainfall region covers the centre and the east of the country including the Nama Karoo, Savannah, Grasslands and Thicket biomes. The summer rainfall season extends from the months of October to April. The winter rainfall region is located along the western coast of South Africa. The rainy season in winter extends from April to September. The year-round rainfall region comprises the southern coast of South Africa. Mean annual precipitation differs considerably and follows an east–west gradient ranging from 1,000 mm along the east coast and escarpment to 200 mm in the Northern Cape Province (Wessels *et al.* 2007).

South Africa's temperatures are strongly influenced by elevation, latitude, and ocean currents.

However, the range of temperature is least at the coast and greatest in the interior (van der Merwe *et al.* 1994). The absolute daily minimum temperature in South Africa was recorded in the Eastern Cape (-16.8°C), and the absolute daily highest temperature (47.8°C) was measured in the lower Orange River Valley (Schulze and McGee 1978). The mean daily minimum temperatures for the coldest month (July) are lowest in the interior of South Africa because of the increased elevation and continental effect (Schulze and McGee 1978). The highest mean annual temperature range or fluctuation in South Africa occurs in the southern Kalahari and along the Orange River valley (Schulze and McGee 1978). Kruger and Shongwe (2004) conducted a temperature trends study for the period from 1960 to 1990 and found that the mean annual temperature for this period was 18.18 °C with a trend of 0.11 °C increase per decade across different stations in South Africa. The same study confirmed that the period 1991 to 2003 had a mean annual temperature of 18.48°C and a trend of 0.09°C per decade. Mucina and Rutherford (2006) identified nine biomes currently in South Africa. A biome is defined as a high-level hierarchical unit, encompassing similar macroclimatic patterns and often subjected to characteristic levels of disturbance events such as grazing and fire (Mucina and Rutherford 2006). The nine South African biomes include Grassland, Savannah, Nama Karoo, Succulent Karoo, Fynbos, Desert, Albany Thicket, Forest and the Indian Ocean Coastal Belt (Figure I). For more details on the characteristics of each biome in South Africa, see Mucina and Rutherford (2006).

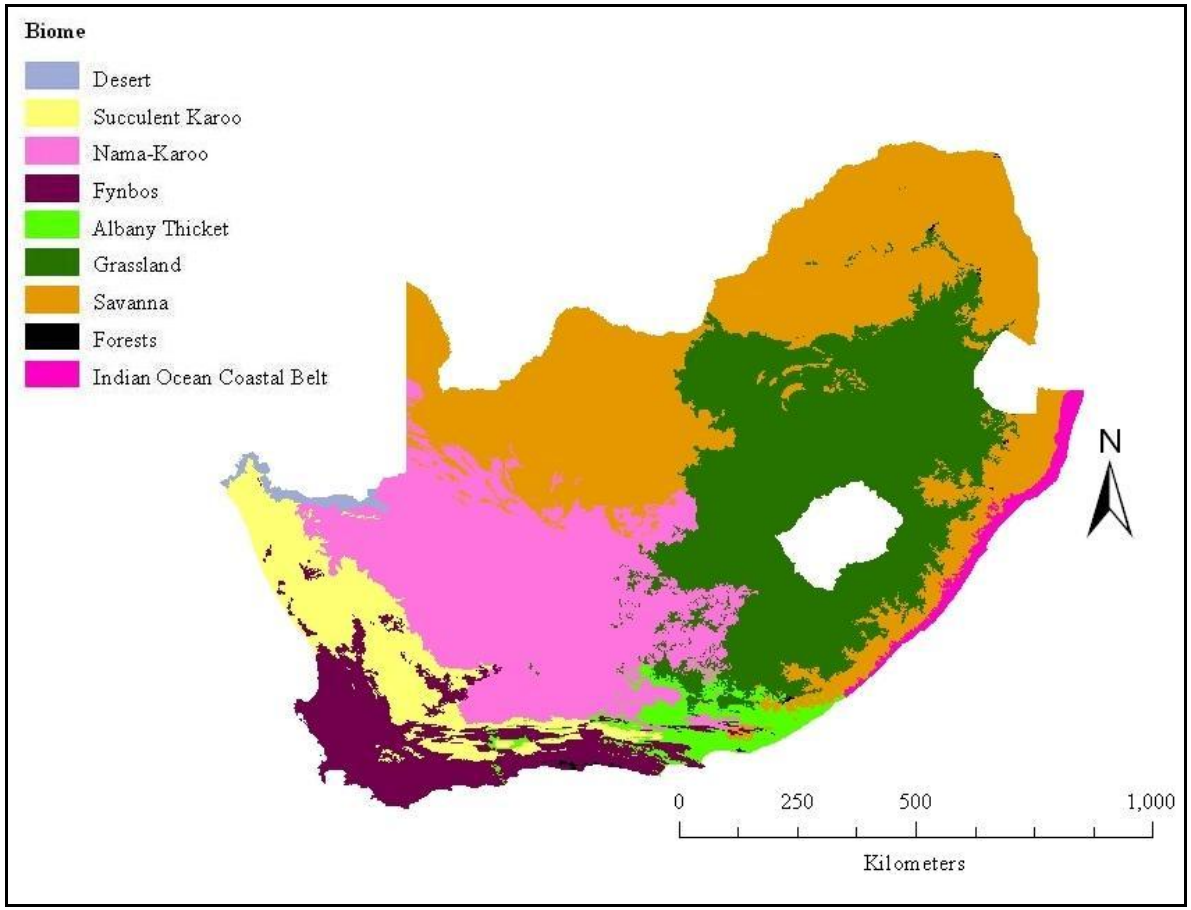

Figure 1. The biomes of South Africa. Extracted from Mucina and Rutherford (2006).

The latest (2006) land-cover classification map of South Africa also incorporates a land use component in its categories (Figure 2). Therefore, the term 'land use/land cover' is used to refer to either land use or land cover for the purposes of this study. Estimates of the land use/land cover types for the year 2000 below, were used as the detailed accounts for land use/land cover characteristics for 2006 were still unpublished at the time. South African land use/land cover information for the year 2000, mapped on the 1:250000 scale, geo-referenced Landsat TM Space maps demonstrated that natural vegetation cover classes constitute 79 percent, wetlands <1 percent and human transformed classes cover the other 20 percent of the South African land surface area (i.e., cultivation, exotic plantations, degraded lands, urban/built-up lands as well as mines and quarries) (Fairbanks *et al.* 2000). However, the principal land transformers in South Africa were cultivation, deforestation, and urbanisation. Fairbanks *et al.* (2000) estimated that 12.11 percent of the country's total area is under cultivation either temporarily or permanently. Degraded land constitutes 4.63 percent of South Africa's total area, while urban/built-up land covers 1.52 percent and forest plantations constitute 1.47 percent of the country's total area. Barren rock covers 0.21 percent, while mines and quarries cover 0.11 percent of the total area.

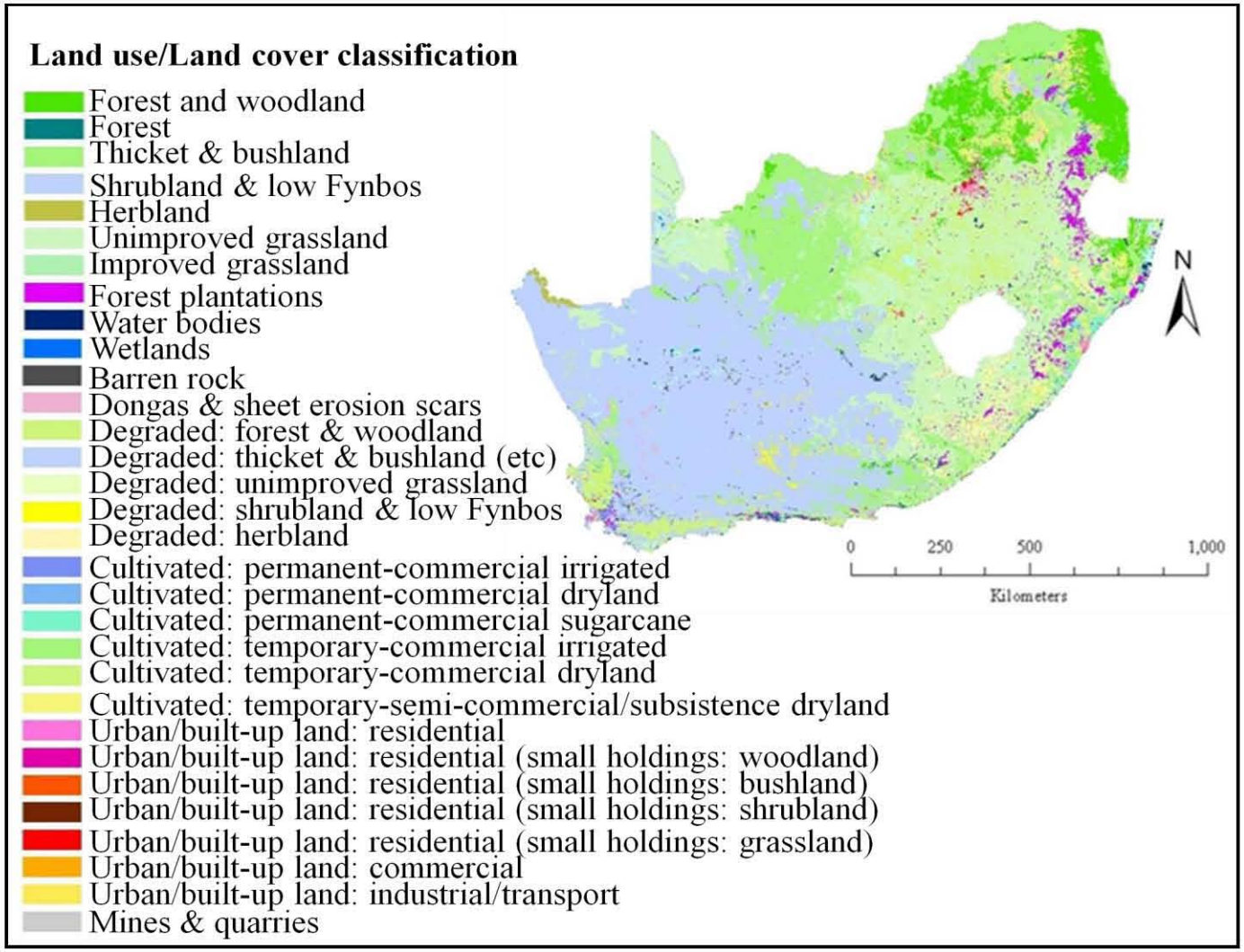

Figure 2. Land use/land cover classification of South Africa (2000).

Sources: The Council for Scientific and Industrial Research (CSIR) and The Agricultural Research Council (ARC) of South Africa**.**

Large parts of South African geological features consist of Precambrian rocks, including the Barberton and Murchison Belts, the Limpopo mobile belt and the Witwatersrand Supergroup, which all belong to the Archean age (Schlüter 2006). The Paleoproterozoic age rocks in South Africa include the Transvaal Supergroup, the Bushveld Complex, the Vredefort Dome and the Waterberg (Mokolian) Supergroup (Schlüter 2006). The Mesoproterozoic age rocks include the Namaqualand Metamorphic Province while the lower Paleozoic incorporates the Cape Fold Belt (Schlüter 2006). However, approximately two-thirds of South Africa's surface is covered by rocks from the Paleozoic to the Mesozoic groups (Schlüter 2006; Viljoen and Reimold 1999). Cenozoic formations of the Kalahari Group cover large parts of northwestern South Africa along the borders with Botswana and Namibia (Schlüter 2006). Further details and descriptions of the South African geological features depicted in Figure 3 are available in (Johnson *et al*. 2006; Schlüter 2006; Viljoen and Reimold 1999; DuToit 1954).

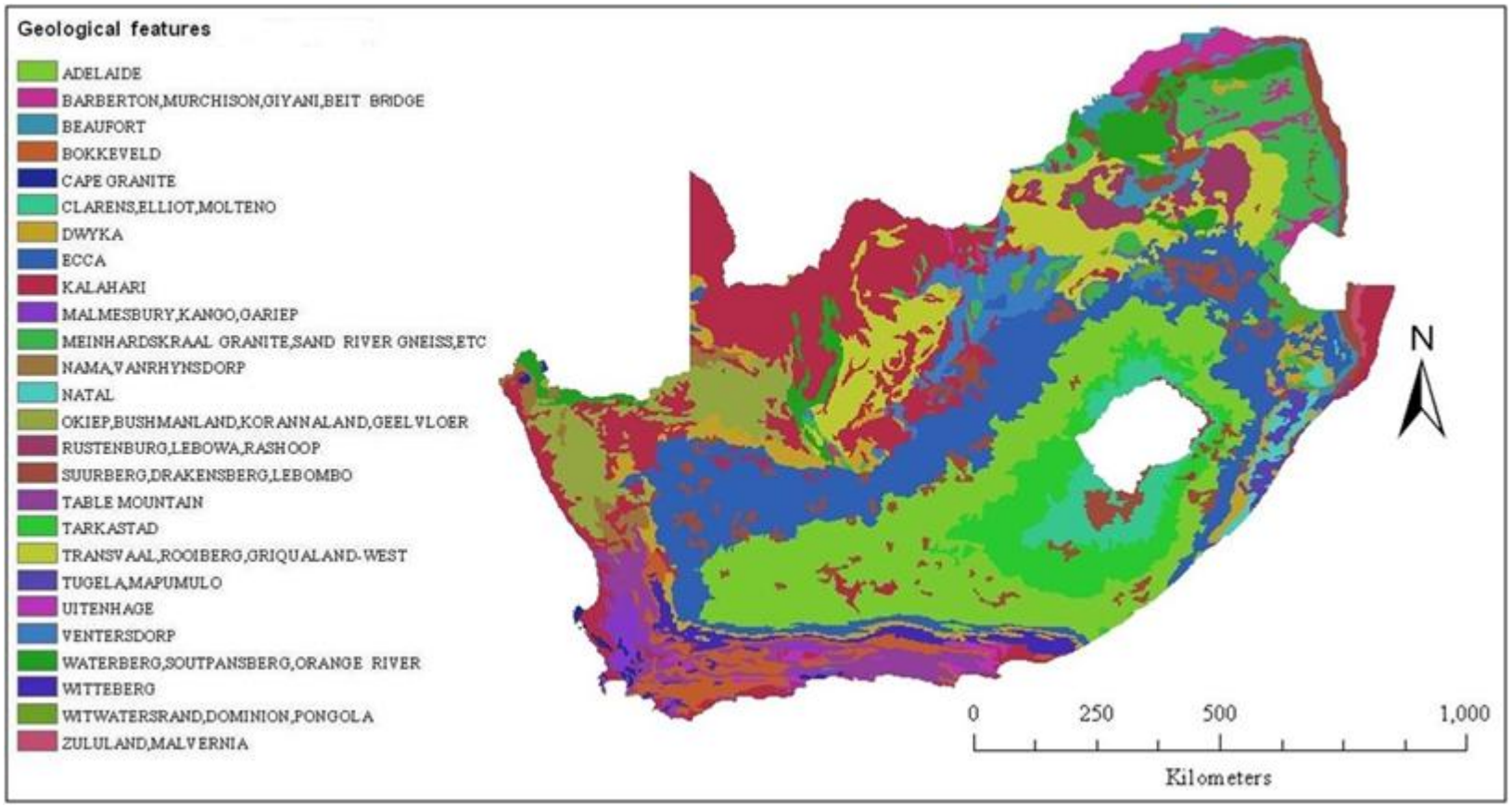

Figure 3. Main geological features of South Africa (2006).

Source: Council for Geoscience.

2.2 Data Collection

Multiple sites (selected according to suitable habitat types for bats) within the Northern Cape Province were sampled between January 2009 and October 2010. Most of the protected areas (National Parks and Nature Reserves) and areas outside formal protection (private farms, mines, buildings, and bridges) in the Northern Cape Province were sampled. Sampled areas for bats comprised of 45 sites from two national parks (the Kgalagadi Transfrontier Park and the Augrabies National Park), five nature reserves (Oorlogskloof, Rolefontein, Rooipoort, Benfontein , and Goegap) and different sites in the Northern Cape Province and along the Orange River (Figure 4).

Sampling methods included primary sampling (mist nets, Harp traps, and hand nets at roosting sites) and secondary sampling methods (acoustic monitoring). These methods were employed simultaneously because prior studies (e.g. Bergallo *et al.* 2003) have indicated that a variety of methods yield more complete species inventories than any single method. The sampling effort has been standardized between sites as far as possible to ensure equal probability of capturing/recording different species of bats.

Mist netting is the most common method used to capture bats (Kunz and Kurta 1988). Each sampling at a site consisted of setting up two to five nets depending on what the site can accommodate. Mist net lengths varied from 3 to 12 m, 2 m high, 4 shelves, and a mesh size of 36 mm. Mist nets were placed at the entrance to non-subterranean bat roosts as well as drinking and foraging sites (ponds, river beds, along potential flyways, open areas, forest edges, and cluttered habitats). Netting was conducted at all temperatures except on nights with rain. Nets were opened at sunset and kept open for ≥3 hours after sunset, as this is the time of peak bat activity (Adam and Hayes 2000). Mist nets were monitored for at least five hours at each sampling site to ensure sampling of species that might forage later at night. Nets were checked as frequently as possible (5-10 minutes) during the sampling period.

Data collected from all captured species included: time, number of individuals captured, species, body mass, forearm length, sex, reproductive status and age (juvenile or adult). The extended

right wing of each bat was also digitally photographed for measurement of wing parameters. These parameters are informative in terms of habitats a species is likely to use (Norberg and Rayner 1987). The geographic coordinates for each sampling site were also recorded using a handheld GPS device.

Similar protocols as those for setting mist nets were used for the placement of harp traps. Harp traps are preferable to mist nets for use in front of subterranean roosts (e.g. caves and mines) where many bats are likely to emerge at once because it is easier to remove bats from the harp trap than from mist nets. The latter are likely to be inundated with bats.

Roost sites (e.g., caves, mines, buildings, bridges) can provide valuable information on bat species that are not easily captured, detected or identified by mist nets, harp traps, and acoustic surveys. Furthermore, it may be necessary to trap bats at the roost to obtain a positive species identification and to ensure that only one species is using the roost. Potential roost sites were searched within the sampling locations. Active roost sites were identified and selected for sampling. Bats within the roost site were captured by using hand nets (if the roost is accessible), or harp trap and mist nets at the entrance or exits of the roost site (if the roost is inaccessible). The echolocation calls of either hand-held (Rhinolophidae or Hipposideridae) or hand-released bats (all other families) were also recorded, as described in the ultrasonic detection section, to confirm species identification.

The ultrasonic detection techniques allow a relative measure of bat activity in an area based on the search phase of their echolocation calls (Griffin 1958). The ability to discriminate and identify individual species depends to some extent on the sophistication of the detecting equipment, but also on the availability of voucher calls. The time expansion bat detector D-240x (Alana Ecology Ltd, England and Wales) was used to record bats in three different situations (Russo and Jones 2002, Waters and Gannon 2004) namely: (1) at roosts emergence for cave dwelling bats, (2) at drinking and foraging sites for bats in free-flight, and (3) from hand-released bats after capture. These calls were used to identify the bat species by comparison with calls in the extensive database of bat calls available from David Jacobs at the University of Cape Town. This database was also supplemented by recording voucher calls from all captured bats identified

using morphological characters and available taxonomic keys (e.g. Skinner and Smithers 1990, Taylor 2000, Monadjem *et al.* 2010).

2.3 Data Compilation and Processing

A database of bat locality records from different museums in South Africa was compiled, in addition to the data collected from field survey of bats in the Northern Cape Province of South Africa during 2009 to 2010. The database yielded a total of 3,442 geo-referenced records of bats after the removal of repeated and incomplete records. Data from Monadjem *et al.* (2010) were also used to verify some of the museums' locality records. The number of records was further reduced by retaining only one locality record per bat species within a quarter degree grid cell. Data reduction was essential before modelling because of the number of duplicate observations and because the scale of the climatic and other environmental variables was described for a quarter degree grid cell (Barker *et al*. 2006). The final database contained 1,990 bat locality records for 56 species of bats. The database for the bat species locality records considered for analyses can be requested from Professor David S Jacobs (David.jacobs@uct.ac.za), Animal Evolution and Systematics Group, Department of Zoology, University of Cape Town, South Africa.

Only bat species with locality records in 10 or more quarter degree grid cells were considered for analyses (Wisz *et al.* 2008; Monadjem *et al*. 2010). Meeting this criterion were 37 of the 56 species comprising 1,502 locality records for analyses. The species considered for analysis belonged to 8 families, namely: Vespertilionidae, 14 species; Rhinolophidae, 8 species; Molossidae, 5 species; Pteropodidae, 4 species; Hipposideridae, 2 species; Miniopteridae, 2 species; Nycteridae, 1 species; and Emballonuridae 1 species (Table 1).

A total of 23 environmental variables, of which 20 were downloaded from the WorldClim database (Hijmans *et al.* 2005; http://www.worldclim.org/current) were considered as potential environmental variables influencing the contemporary distribution of bats in South Africa. Based

on the Bioclim database, nineteen of the bioclimatic variables were considered as key biological determinants for the ecological tolerance of a species (Graham and Hijmans 2006; Maurienne *et al.* 2009). These nineteen variables were generated from the monthly averages of minimum, maximum and mean temperatures as well as from average precipitation for the period 1950-2000 (Nix 1986, Hijmans *et al.* 2005). Elevation data for South Africa, measured in (m asl), were also downloaded from the Bioclim database. All the Bioclim variables were continuous variables with 10 arc-minutes spatial resolutions. Three categorical variables were also considered as potentially influencing the distribution of bats in South Africa. The first category included the *Digital vegetation biomes map for South Africa (vegetation biome)* extracted from Mucina and Rutherford (2006). The second category included the latest *National land cover characteristic digital map for South Africa 2006 (land use/land cover)* produced by The Council for Scientific and Industrial Research (CSIR) and The Agricultural Research Council (ARC) in South Africa; and was made available by the Cape Action for People and the Environment (C.A.P.E), and the South African National Biodiversity Institute (SANBI), Kirstenbosch Botanical Gardens, Cape Town. The third category included the *Geology map of South Africa (main geological features digital map)* (Council for Geoscience 2006), obtained from the GIS laboratory of the Department of Engineering and the Built Environment, University of Cape Town, South Africa.

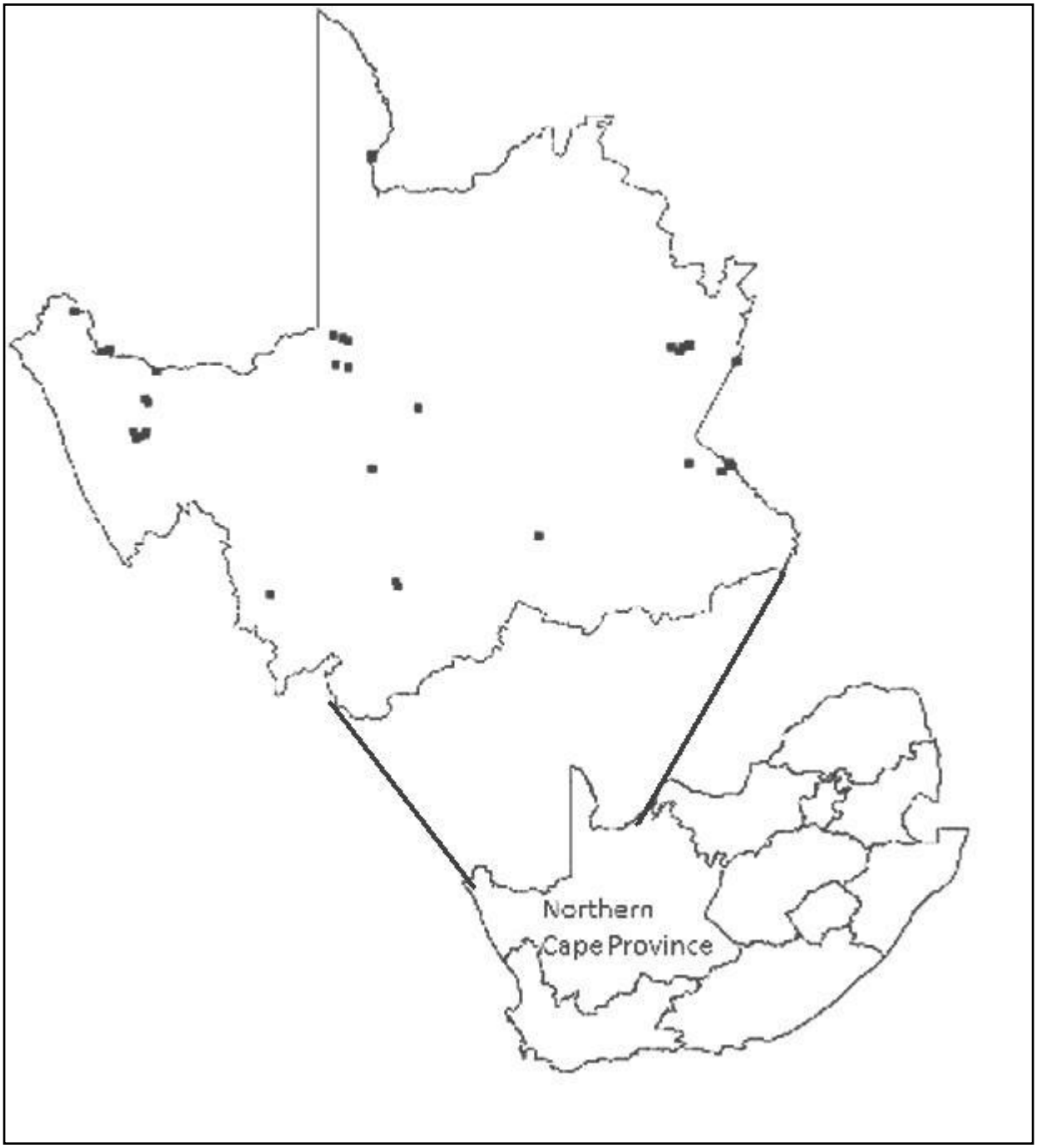

Figure 4. Locations where bats were surveyed in the Northern Cape Province of South Africa from 2009-2010. Data were combined with the bat locality records for the rest of South Africa for use in MaxEnt. For details of species accounts and names of locality records, see Appendix 6.

Table 1. South African bat species and the number of locality records for each species considered for analysis using MaxEnt version 3.3.3a software.

Family	Species	Number of locality points
Emballonuridae	*Taphozous mauritianus*	29
Hipposideridae	*Cloeotis percivali*	11
	Hipposideros caffer	56
Miniopteridae	*Miniopterus fraterculus*	25
	Miniopterus natalensis	133
Molossidae	*Sauromys petrophilus*	30
	Tadarida aegyptiaca	140
	Chaerephon pumilus	56
	Mops condylurus	30
	Mops midas	12
Nycteridae	*Nycteris thebaica*	129
Pteropodidae	*Epomophorus wahlbergi*	65
	Rousettus aegyptiacus	30
	Epomophorus crypturus	17
	Eidolon helvum	21
Rhinolophidae	*Rhinolophus clivosus*	152
	Rhinolophus capensis	36
	Rhinolophus darlingi	53
	Rhinolophus denti	12
	Rhinolophus blasii	13
	Rhinolophus simulator	49
	Rhinolophus hildebrandtii	14
	Rhinolophus swinnyi	15
Vespertilionidae	*Nycticeinops schlieffeni*	26
	Pipistrellus hesperidus	37
	Cistugo lesueuri	14
	Eptesicus hottentotus	23
	Myotis tricolor	42
	Neoromicia capensis	311
	Neoromicia zuluensis	20
	Scotophilus dinganii	86
	Scotophilus viridis	17
	Neoromicia nana	52
	Neoromicia melckorum	24
	Myotis welwitschii	13
	Pipistrellus rusticus	33
	Kerivoula lanosa	12

All environmental variables were re-sampled to a quarter degree spatial resolution using ArcMap 9.2 (ESRI) so as to conform to the division of the study area into 1,967 equal area quarter degree grid cells for data analysis purposes. All variables downloaded from the WorldClim database (continuous variables) were tested for multicolinearity using STATISTICA version 10 software (StatSoft, Tulsa, Oklahoma, USA). The test was performed by examining cross-correlations (Pearson's correlation coefficients, r) among the variables based on the 1990 bat locality records for the different bat species in South Africa. Only one variable was then selected from a set of highly correlated variables in case of positive ($r \geq 0.7$) or negative ($r \leq -0.7$) correlation for inclusion in the model (Kumar and Stohlgren 2009). The choice of the variable was based on a Jackknife test of variable importance. A preliminary MaxEnt model was run for each species with all the variables and then the variable which contributed most to the training gain of the model was selected, from amongst the correlated variables.

Environmental variables were grouped into several broad categories and eleven temperature variables all measured in (°C) were obtained from the WorldClim database. All temperature data downloaded from the WorldClim-Global Climate Data are in °C * 10. This allows for much reduced file sizes which is important as for many downloading large files remains difficult (Hijmans *et al.* 2005). The eleven temperature variables downloaded from the WorldClim include; annual mean temperature, diurnal temperature range (the difference between the daily maximum and minimum temperature), isothermality (mean diurnal range/temperature annual range), temperature seasonality (coefficient of variation), maximum temperature of the warmest month, minimum temperature of the coldest month, temperature annual range (the maximum temperature of warmest period minus the minimum temperature of coldest period), mean temperature of the wettest quarter, mean temperature of the driest quarter, mean temperature of the warmest quarter and mean temperature of the coldest quarter. Precipitation variables, all measured in (mm) were also grouped into eight categories and obtained from the same source: annual precipitation, precipitation in the wettest month, precipitation in the driest month, precipitation seasonality (coefficient of variation), precipitation in the wettest quarter, precipitation in the driest quarter, precipitation in the warmest quarter and precipitation in the coldest quarter. Elevation, measured in (m asl.) and also downloaded from the WorldClim

database, was further placed in a separate category to represent topographic variables. Furthermore, biophysical variables which are all categorical were grouped into three groups. The first category included the *Digital vegetation biomes map for South Africa (vegetation biome),* which included 8 sub-categories (Table 2). The second category included the *National land cover digital map of South Africa (land use/land cover),* which included 26 sub-categories (Table 3). The third category included the *Digital geological map of South Africa (geology)* which included 26 sub-categories (Table 4). All 23 environmental variables (layers) were converted from the ESRI shape files (shp.) into (asc.) raster files using ArcGIS 9.2 for use in the MaxEnt 3.3.3a modelling software.

Some land use/land cover classifications depicted in Figure 2 did not appear in Table 2 as the pixels representing these features were very small in size compared to the scale of the digital map and did not show in the layers' conversion process from ESRI shape files (shp.) into (asc.) raster files using ArcGIS 9.2. These land use/land cover features included: degraded herbland; urban/built-up land, industrial transport; urban/built-up land, residential (small holdings: woodland); urban/built-up land, residential (small holdings: bushland), and urban/built-up land, residential (small holdings: shrubland). The reduction of land use/land cover from 31 to 26 categories resulted in a loss of about 16 percent of the data.

Table 2. Codes denoting the vegetation biome categories of South Africa used in MaxEnt analysis, from Figure 1.

Code	Vegetation biome
0	Succulent Karoo
1	Fynbos
2	Nama Karoo
3	Savanna
4	Grassland
5	Albany Thicket
6	Indian Ocean Coastal Belt
7	Desert

Table 3. Codes denoting the National land cover/land use classification of South Africa (2006) (Figure 2) used in MaxEnt analysis. The digital map was provided by C. A. P. E. and SANBI.

Code	Land use/Land cover type
1	Cultivated: temporary commercial – irrigated
2	Shrubland and low fynbos
3	Cultivated: permanent commercial – irrigated
4	Wetlands
5	Thickets bushland
6	Unimproved grassland
7	Mines and quarries
8	Waterbodies
9	Degraded: Thickets and bushland etc.
10	Forest plantations
11	Cultivated: temporary commercial dryland
12	Barren rock
13	Urban/built-up land: residential
14	Herbland
15	Cultivated: permanent commercial dryland
16	Degraded: unimproved grassland
17	Forest and woodland
18	Degraded: shrubland and low fynbos
23	Improved grassland
24	Dongas and sheet erosion scars
25	Urban/built-up land: commercial
26	Forest
27	Cultivated: temporary semi-commercial/subsistence-dryland
28	Urban/built-up land: residential (small holding: grassland)
30	Degraded: forest and woodland
32	Cultivated: permanent commercial – sugarcane.

Table 4. Codes denoting the geology map of South Africa (Figure 4) used in the MaxEnt analysis.

Code	Geology type
1	Beaufort
2	Barberton, Murchison, Giyani, Beit Bridge
3	Suurberg, Drakensberg, Lebombo
4	Zululand, Malvernia
5	Waterberg, Southpansberg, Orange River
6	Kalahari
7	Meinhardskraal Granite, Sandriver Geinss, etc.
8	Dwyka
9	Rusternburg, Lebowa, Rashoop
10	Transvaal, Rooiberg, Griqualand-West
11	Ventersdorp
12	Ecca
13	Witwatersrand, Dominion, Pongola
14	Okiep, Bushmanland, Korannaland, Geelfloer
15	Nama, Vanrhynsdorp
16	Adelaide
17	Natal
18	Clarens, Elliot, Molteno
19	Tarkastad
20	Witteberg
21	Cape Granite
22	Tugela, Mapumulo
23	Bokkeveld
24	Malmesbury, Kango, Gariep
25	Table Mountain
26	Uitenhage

2.4 Data Analysis

2.4.1 MaxEnt Software

The maximum entropy MaxEnt version 3.3.3a (Phillips *et al.* 2004, 2006) modelling technique was used to predict the environmental correlates of South African bat distributions. MaxEnt is a general-purpose machine-learning method that estimates spatial distributions from presence-only data (Phillips *et al.* 2006; Phillips and Dudik 2008). Entropy in the context of probability theory and statistics measures the amount of information that is contained in a random variable or unknown quantity. MaxEnt estimates the probability distribution of an entity by finding the probability distribution of maximum entropy, that is, the closest to uniform. MaxEnt software is a relatively new technique and has only recently been applied to modelling species distributions (Phillips *et al.* 2006). Further information about the MaxEnt software and its operation can be found at http://www.cs.princeton.edu/ ~schapire/maxent (or see Phillips *et al.* 2006).

2.4.2 Model Developments with MaxEnt

MaxEnt was chosen over other available species distribution modelling (SDM) techniques, as it is a presence-only modelling technique (it does not require absence data). In addition, MaxEnt is one of the SDM techniques that is robust for small sample sizes (i.e., between 10-30 occurrence records) (Wisz *et al.* 2008). Further, MaxEnt yields better predictions compared to other SDM techniques (Phillips *et al*. 2006, Yun-sheng *et al*. 2007, Hernandez *et al.* 2008). For example, Phillips *et al*. (2006) performed a continental-scale study using two Neotropical mammals: a lowland species of sloth, *Bradypus variegatus*, and a small montane murid rodent, *Microryzomys minutes*. The researchers compared Maxent predictions with those of a commonly used presence-only modelling method, the Genetic Algorithm (GARP) to investigate the accuracy of each modelling technique. Their findings reveal that the area under the ROC curve (AUC) was almost always higher for Maxent compared to (GARP) indicating better discrimination of suitable versus unsuitable areas for the species. In addition, Hernandez *et al.* (2008) compared the performance of three species distribution modelling techniques (Maxent, Mahalanobis Typicalities and Random Forests) at predicting distributions of eight bird and eight mammal

species endemic to the eastern slopes of the central Andes. Their results show that Maxent performed well compared to the other two techniques for all species tested regardless of the number of records or the extent of occurrence. For species with small numbers of sample localities (N = 5–21), Maxent produced the most consistently successful results compared to the other two modelling techniques.

It is a pre-requisite in MaxEnt that environmental variables are in American Standard Code for Information Interchange (ASCII) grid format and that species occurrences are provided as a ScanVec CASmate (SCV) file. The input data, namely environmental variables and species occurrence records were prepared using ArcGIS 9.2 software and Microsoft Windows Excel, respectively. Both the environmental layers and species occurrence records were further geo-referenced to the official coordinate system of South Africa (Hartebeesthoek 94 co-ordinate system). MaxEnt allocates a probability of occurrence to each cell in the study area and the sum of this probability must be equal to one. Therefore, the model predictions were presented as graded probabilities for each grid cell ranging from zero (low) to one (high) probability of occurrence and the output format was then imported to the ArcGIS 9.2 software. Additionally, the Jackknife test for variable importance and the response curves were also presented.

Prior to running the models, the parameters were set as follows: regularisation multiplier to 1, maximum number of background points (pixels) to 10,000, replicates to 10, replicated run type to crossvalidate, maximum iterations to 500 and conversion threshold to 10^{-5}. The environmental variables 'features' selection was performed automatically following the default rules set according to the number of presence records.

2.4.3 Evaluation of MaxEnt Model Performance

The assessment of model validity is a fundamental procedure in predictive model development. Model assessment helps in deciding the suitability of a model for a particular purpose (Pearce and Ferrier 2000). Several approaches exist for assessing model predictive performance such as: methods for comparing predictions against data obtained independently (splitting), methods for

selecting thresholds of occurrence and other different test statistics (Pearson 2007). However, there is no consensus on preferred approaches for use in different model performance assessments. Rather, the choice depends on the aim of the modelling, the modelling method used and the types of data available (Pearson 2007).

The aim of this analysis was to produce a continuous predictive map displaying the probability of an occurrence ranging from zero (low) to one (high) probability. A continuous prediction takes into account all of the information provided by the model. In contrast, a binary prediction (presence, absence) depends on a threshold selection. As the available data for this analysis was the presence-only data (i.e., no absence data was available), the threshold-independent assessment of model performance was selected.

The presence records were split into training and test data. Training data are generally used for generating the model while test data are used to validate the resulting model. Model performance can differ according to the amount of data set aside for building the test model. Therefore, an assessment of the average behaviour of the MaxEnt model was prepared by using 10 random partitions of the presence records (Phillips *et al.* 2006). Each partition was created by selecting a test percentage of 30 in the MaxEnt settings tab (i.e., this implies that the software randomly selects 70 percent of the occurrence locality records for generating the model, leaving 30 percent for testing the model).

The Area Under the Receiver Operating Characteristic Curve (AUC) statistics was then selected to assess the model performance. This test provides a single measure of predictive performance across the full range of possible thresholds (Deleo 1993). The AUC test has recently been applied to a variety of classification problems in machine-learning (for example Provost and Fawcett 1997) and in the evaluation of models of species distributions (Elith 2002, Fielding and Bell 1997). The AUC performance was proven to be generally good (Bradley 1997)

The AUC test is derived from the Receiver Operating Characteristic (ROC) Curve. The ROC curve analysis is generally used in presence-absence modelling. In MaxEnt however, the

corresponding absence data are background points (Phillips *et al.* 2006). In other words, the AUC uses the background data instead of absence data to measure the ability of the algorithm to discriminate between a suitable environmental condition and a random analysis pixel (background). It does not discriminate directly between suitable and unsuitable conditions as in presence-absence modelling (Phillips *et al.* 2006).

In MaxEnt, the ROC curve plots sensitivity (i.e., proportion of observed presences correctly predicted) against '1-specificity' (proportion of observed absences incorrectly predicted). The advantages of using sensitivity and specificity are that these measures take into account the following components: observed presences, true absences, false presences and false absences (Pearson 2007). The AUC describes a proportion of the total area of the square defined by the axes (Swets 1988). It has values usually ranging from 0.5 to 1.0. The value 0.5 for AUC means the model only predicts accurately 50 percent of the time (i.e., random prediction or no discrimination). In addition, the value 1.0 for AUC means ideal discrimination (Engler *et al.* 2004; Metz 1978). Subjective guidelines can be used to choose among the values of test statistics that are considered reliable for model performance. However, Hosmer and Lemeshow (2000) suggest that AUC can be classified as follows: AUC= 0.5, no discrimination; 0.7<AUC<0.8, acceptable; 0.8<AUC<0.9, excellent; and AUC>0.9, outstanding.

As average training gain is relatively more sensitive to the average AUC value (Yost *et al.* 2008), this method was also used to decide on the best performing model to be selected as the final model for each bat species. Hence, the best model would be the one that contains the fewest predictor variables with an average training gain that does not differ significantly from that of the subsequent larger model, but differs significantly from the smaller model that follows. The overlap between the 95 percent confidence interval as significance criteria in the training gain averages was employed to decide on the best final model.

MaxEnt models can also be evaluated visually by inspecting how well the probability values in the output grid conform to the points of presence records (Yost *et al.* 2008). MaxEnt generates an output picture of the model prediction for the GIS grids that represent each predictor variable. In

a good MaxEnt prediction map, one expects areas with a high probability of occurrence to be the areas where the majority of presence records are situated. In contrast, areas of low probability of occurrence should contain few to no presence records (Yost *et al.* 2008).

The main purpose of this study was to build a model that uses the smallest number of best possible environmental predictors. Therefore, firstly, a model was built for each species using the parameter settings mentioned in the previous paragraphs. To choose the best model, the procedures of MaxEnt's Jackknife test of variable importance were followed to assess the relative influence of each predictor variable.

A description of the execution of the procedures follows below (Yost *et al.* 2008): 1) A full model was run 10 times for each species, including all pre-selected environmental variables (i.e., non-correlated variables) for each species so as to assess the average behaviour of the MaxEnt model, following Phillips *et al.* (2006); 2) Using the Jackknife test of variable importance, the variable that contributed the least to the model gain was eliminated; 3) The model was subsequently re-run with the remaining variables; 4) The process was repeated until only one variable was retained; 5) The overlap between the 95 percent confidence interval in the average training gain for the 10 models was used to choose the best model (i.e., the model with the least number of predictors and training gain not significantly different from that of the subsequent larger model); 6) Finally, the best model was run with all of the occurrence data for a particular species in order to take advantage of all available data, following Philips *et al.* (2006). The best model with the full set of occurrence records was considered the final reduced model to obtain the best estimate of the species distribution and for creating a GIS probability distribution map.

Chapter 3

RESULTS

3.1 The Influence of Environmental Variables on the Distribution of South African Bat Species

The reduced MaxEnt model (i.e., the best model after model reduction) grouped bat species independently of their phylogenetic (i.e., family) relationships, on the basis of the predictor variables which best explained their distributions. For the 37 bat species considered in this analysis, the distributions of 10 species were best predicted by precipitation variables, those of another 12 species by temperature variables and those of the remaining 15 species by biophysical variables.

Among the 10 species of South African bats whose distributions were associated most strongly with precipitation variables (Table 5), the distributions of three, *Epomophorus wahlbergi, Rhinolophus clivosus* and *Pipistrellus hesperidus* were associated most strongly with annual precipitation. The distributions of another four species, *Eidolon helvum, Mops midas, Pipistrellus rusticus* and *Rhinolophus hildebrandtii* were most affected by precipitation seasonality. Of the three remaining species the distributions of two, *Rhinolophus blasii* and *Rhinolophus simulator* were associated most strongly with the amount of precipitation in the warmest quarter of the year and the distribution of the last species in this group, *Neoromicia melckorum* was influenced by the amount of precipitation in the coldest quarter.

Of the 12 species of bats that were influenced by temperature variables (Table 6), the distribution of six, *Scotophilus dinganii, Scotophilus viridis, Chaerephon pumilus, Mops condylurus, Hipposideros caffer* and *Epomophorus crypturus*, were associated most strongly with the mean temperature of the coldest quarter. The distributions of two species, *Rhinolophus swinnyi* and *Kerivoula lanosa,* were most affected by temperature seasonality. The distribution of two species, *Nycteris thebaica* and *Neoromicia nana* were best predicted by the minimum temperature of the coldest month. Of the two remaining species in this group, the distribution of

one, *Miniopterus fraterculus*, was most affected by annual temperature range and that of the last species, *Nycticeinops schlieffeni*, by annual mean temperature.

Of the 15 species whose distributions appear to be strongly influenced by biophysical variables (Table 7), the distributions of eight were best predicted by geology: *Cistugo lesueuri, Cloeotis percivali, Eptesicus hottentotus, Miniopterus natalensis, Myotis tricolor, Rhinolophus darlingi, Sauromys petrophilus* and *Rousettus aegyptiacus.* The distribution of six species, *Neoromicia capensis, Neoromicia zuluensis, Rhinolophus denti, Tadarida aegyptiaca, Taphozous mauritianus* and *Myotis welwitschii* responded to land use/land cover. The distribution of only one species, the endemic *Rhinolophus capensis*, was best predicted by biome.

Below follows a detailed description of the MaxEnt models for each of the 37 species of South African bats grouped by the environmental variable which was found to limit their distribution the most.

3.1.1 Models for the 10 South African Bat Species Influenced by Precipitation

3.1.1.1 Models for the Three South African Bat Species Influenced by Annual Precipitation

3.1.1.1.1 *Epomophorus wahlbergi*

A total of nine predictor variables were considered for modelling the distribution of *Epomophorus wahlbergi* (Table 8). The name of each variable as it was removed from the full model is given in the column titled “predictor variable removed” (Table 8). The average training AUC values generated by MaxEnt for all model partitions across the full range of possible thresholds were > 0.5 (AUC ranges between 0.87-0.90), indicating a better-than-random fit

(Table 8). The average training AUC values suggest that model predictions could be correct as high as 90 percent of the time in predicting the occurrence of *Epomophorus wahlbergi* (Table 8). Additionally, there were no significant differences (Mann-Whitney Test p's <0.05, Table 8) among the subsequent individual training models in the AUC values for the models with more variables included (i.e., models 9-4) (Table 8). In contrast, in models with fewer variables (i.e., models 3-1), AUC values differed significantly from the subsequent more complex models (Table 8). In general, average AUC values did not exhibit a trend as model complexity decreased. However, the AUC value dropped slightly in the one-variable model containing only the annual mean temperature.

The Jackknife test of variable importance found that the average training gain declined as variables were removed from the full model (Figure 4). The 95 percent confidence interval as a significance criterion in training gain averages illustrated that the two-variable model containing the annual precipitation and mean temperature of the coldest quarter was not significantly different from the seven larger models but was significantly different from the smaller one-variable model (Figure 4). The two-variable model was therefore used to build the final model for *Epomophorus wahlbergi.*

The final two-variable model for Epomophorus wahlbergi

Based on all 65 presence records for *Epomophorus wahlbergi,* the average training gain for the two-variable model was 1.354. MaxEnt's internal Jackknife test of variable importance proved that annual precipitation increased the average training gain the most (the black bars, Figure 5), suggesting that it was the single most important variable in the model. In addition, the same variable decreased the average training gain the most when omitted from the full model (the white bars, Figure 5). Analysis of the variable contribution suggests that annual precipitation contributed 60.3 percent to the model while the mean temperature of the coldest quarter contributed 39.7 percent. Thus both annual precipitation and mean temperature of the coldest quarter influenced model prediction by a single peak response skewed to the left (Figure 7 a; b).

The MaxEnt response curve (Figure 7a) indicated that the log response for *Epomophorus wahlbergi* reaches approximately 0.85 as the annual precipitation changes from 200 to 1,250 mm. The value of the log response curve started at zero for the lowest values (200 mm) of annual precipitation shown in the graph, and subsequently increased gradually to 0.85 at 1,250 mm where the curve flattened. The model thus suggests that the limiting value for annual precipitation for this species is approximately 200 mm or less. An annual precipitation of about 1,250 mm is favourable for this species.

Concerning the second most limiting environmental factor for *Epomophorus wahlbergi* after annual precipitation, the response curve (Figure 7b) illustrated that the log response for this species reaches around 0.99 as the mean temperature of the coldest quarter changes from 4.0 to 19°C. The value of the log response curve started at zero for the lowest value (about 4.0°C) of mean temperature of the coldest quarter shown in the graph and then increased gradually to 0.99 at about 19°C where the curve reached an asymptote. Favourable mean temperatures during the coldest three months of the year ranged from 18 to 20°C. Over this temperature range the graph showed the highest jump in the value of the log response from about 0.7 to 0.98. The model thus suggests that the limiting value for the mean temperature of the coldest quarter of the year ranged from 18 to 20°C.

Probability of occurrence map for Epomophorus wahlbergi

A two-variable model constructed from all 65 presence records was calculated in order to create the probability of occurrence map for *Epomophorus wahlbergi* in South Africa. The predictor variables used in the model included the annual precipitation (as the strongest limiting predictor) and the mean temperature of the coldest quarter (as the second most limiting predictor) (Figure 5). The MaxEnt probability of occurrence map (Figure 8) demonstrated a broad agreement with actual *Epomophorus wahlbergi* occurrence records in South Africa. The areas with a high concentration of occurrence records for *Epomophorus wahlbergi* (eastern part of South Africa, along the coast from the Eastern Cape throughout KwaZulu-Natal), were correctly associated with regions of high probability of occurrences predicted by MaxEnt. However, the probability of occurrence for *Epomophorus wahlbergi* was relatively low westward away from the Indian

Ocean Coast. This suggests that the distribution of this species in South Africa follows the precipitation trends in South Africa which decreases westward.

Table 5. The final model parameters for bat species whose distributions are mostly influenced by precipitation. The respective AUC p-values and Z scores from the Mann-Whitney U test for training data are statistical results from a comparison between the final model selected and the next model with the highest number of variables.

Family	**Bat species**	**Variables retained in the final model from the MaxEnt Jackknife test**						**Mann-Whitney U test for the model selected as the final model from the MaxEnt splitting method**			
		Number of variables	The most important variable	% contribution	The second most important variable	% contribution	Other variables in the model	Average test AUC	Average training AUC	UC p-value	UC Z score
Pteropodidae	*Epomophorus wahlbergi*	2	annual precipitation	60.3	mean temperature of coldest quarter	39.7		0.90	0.90	.002	.10
Rhinolophidae	*Rhinolophus clivosus*	2	annual precipitation	57.2	geology	42.8		0.72	0.78	.026	.23
Vespertilionidae	*Pipistrellus hesperidus*	2	annual precipitation	84.7	land use/land cover	15.3		0.89	0.94	.04	.01
Pteropodidae	*Eidolon helvum*	2	precipitation seasonality	57.6	precipitation of warmest quarter	42.4		0.74	0.86	.38	.87
Molossidae	*Mops midas*	2	precipitation seasonality	60.5	temperature seasonality	39.5		0.92	0.95	.006	.76

Vespertilionidae	*Pipistrellus rusticus*	3	precipitation seasonality	56.9	land use/land cover	27.7	geology	0.89	0.95	.31	.02
Rhinolophidae	*Rhinolophus hildebrandtii*	2	precipitation seasonality	57	geology	43		0.88	0.94	.045	.00
Rhinolophidae	*Rhinolophus blasii*	2	precipitation of warmest quarter	57.3	geology	42.7		0.83	0.89	.08	.78
Rhinolophidae	*Rhinolophus simulator*	2	precipitation of warmest quarter	75.7	geology	24.3		0.90	0.91	.038	.08
Vespertilionidae	*Neoromicia melckorum*	2	precipitation of coldest quarter	70.3	precipitation of warmest quarter	29.7		0.85	0.82	.005	.83

Table 6. Final model parameters for bat species whose distributions are mostly influenced by temperature. The respective AUC p-values and Z scores from the Mann-Whitney U test for training data are statistical results from a comparison between the final model selected and the next model with the highest number of variables.

Family	**Bat species**	**Variables retained in the final model from the MaxEnt Jackknife test**						**Mann-Whitney U test for the model selected as the final model from the MaxEnt splitting method**			
		Number of variables	The most important variable	% contribution	The second most important variable	% contribution	Other variables in the model	Average test AUC	Average training AUC	AUC p-value	AUC Z score
Vespertilionidae	*Scotophilus dinganii*	3	mean temperature of coldest quarter	48.4	precipitation of warmest quarter	39.7	land use/land cover	0.88	0.91	0.005	2.83
Vespertilionidae	*Scotophilus viridis*	2	mean temperature of coldest quarter	91.6	geology	8.4		0.98	0.95	0.002	3.14
Molossidae	*Chaerephon pumilus*	2	mean temperature of coldest quarter	75.6	Precipitation of warmest quarter	24.4		0.94	0.93	0.002	3.06
Molossidae	*Mops condylurus*	2	mean temperature of coldest quarter	91.8	geology	8.2		0.93	0.97	0.15	1.44
Hipposideridae	*Hipposideros caffer*	3	mean temperature of coldest quarter	62.8	precipitation of warmest quarter	27	geology	0.93	0.95	0.01	0.25
Pteropodidae	*Epomophorus crypturus*	2	mean temperature of coldest quarter	66.4	Land use/Land cover	33.6		0.92	0.94	0.08	1.78
Rhinolophidae	*Rhinolophus swinnyi*	2	temperature seasonality	68.8	geology	31.2		0.94	0.97	0.004	2.91

Family	Bat species	Variables retained in the final model from the MaxEnt Jackknife test						Mann-Whitney U test for the model selected as the final model from the MaxEnt splitting method			
		Number of variables	The most important variable	% contribution	The second most important variable	% contribution	Other variables in the model	Average test AUC	Average training AUC	AUC p-value	AUC Z score
Vespertilionidae	*Kerivoula lanosa*	4	temperature seasonality	61.6	geology	16.8	land use/land cover & biome	0.84	0.99	.76	.31
Hipposideridae	*Nycteris thebaica*	3	minimum temperature of coldest month	57.2	precipitation of warmest quarter	25	geology	0.71	0.77	0.003	2.99
Vespertilionidae	*Neoromicia nana*	3	minimum temperature of coldest month	67.7	precipitation of warmest quarter	28.2	geology	0.94	0.96	0.52	0.64
Vespertilionidae	*Miniopterus fraterculus*	3	temperature annual range	62.5	land use/land cover	23.3	geology	0.89	0.96	0.27	1.1
Vespertilionidae	*Nycticeinops schlieffeni*	2	annual mean temperature	89	geology	11		0.90	0.96	0.02	2.31

Table 7. Final model parameters for bat species whose distributions are mostly influenced by biophysical variables (geology, land use/land cover and biome). The respective AUC p-values and Z scores from the Mann-Whitney U test for training data are the statistical results from a comparison between the final model selected and the next model with the highest number of variables

Family	**Bat species**	**Variables retained in the final model from the MaxEnt Jackknife test**						**Mann-Whitney U test for the model selected as the final model from the MaxEnt splitting method**			
		Number of variables	The most important variable	% contribution	The second most important variable	% contribution	Other variables in the model	Average test AUC	Average training AUC	AUC p-value	AUC Z score
Vespertilionidae	*Cistugo lesueri*	3	geology	48.7	land use/land cover	40.8	mean temperature of coldest quarter	0.74	0.90	0.94	0.08
Hipposideridae	*Cloeotis percivali*	*3*	geology	48.8	land use/land cover	26	isothermality	0.89	0.96	0.21	1.25
Vespertilionidae	*Eptesicus hottentotus*	*2*	geology	70.6	land use/land cover	29.4		0.68	0.88	0.73	0.34
Miniopteridae	*Miniopterus natalensis*	*3*	geology	40.1	land use/land cover	36.8	precipitation of coldest quarter	0.72	0.80	0.12	1.55
Vespertilionidae	*Myotis tricolor*	*3*	geology	36.6.1	maximum temperature of the warmest month	33.8	Land use/land cover	0.78	0.89	0.01	2.46
Rhinolophidae	*Rhinolophus darlingi*	*2*	geology	57.1	land use/land cover	42.9		0.76	0.86	0.14	1.47

Family	Bat species	Variables retained in the final model from the MaxEnt Jackknife test						Mann-Whitney U test for the model selected as the final model from the MaxEnt splitting method			
		Number of variables	The most important variable	% contribution	The second most important variable	% contribution	Other variables in the model	Average test AUC	Average training AUC	AUC p-value	AUC Z score
Molossidae	*Sauromys petrophilus*	*2*	geology	63.4	land use/land cover	36.6		0.69	0.89	0.57	0.57
Pteropodidae	*Rousettus aegyptiacus*	4	geology	23	annual precipitation	35.4	Biome and land use/land cover	0.84	0.94	0.004	2.87
Vespertilionidae	*Neoromicia capensis*	2	land use/land cover	66.9	Geology	33.1		0.60	0.70	0.21	1.25
Vespertilionidae	*Neoromicia zuluensis*	1	land use/land cover	67.4	mean temperature of coldest quarter	32.4		0.93	0.95	0.79	0.26
Rhinolophidae	*Rhinolophus denti*	2	land use/land cover	77.5	Geology	22.5		0.87	0.91	0.36	0.91
Molossidae	*Tadarida aegyptiaca*	2	land use/land cover	54.6	precipitation of driest quarter	45.4		0.52	0.61	0.19	1.32
Emballonuridae	*Taphozous mauritianus*	3	land use/land cover	50.9	temperature annual range	28.4	geology	0.74	0.90	0.73	0.34

Family	Bat species	Variables retained in the final model from the MaxEnt Jackknife test						Mann-Whitney U test for the model selected as the final model from the MaxEnt splitting method			
		Number o variables	The most important variable	% contributior	The second most important variable	% contributior	Other variables in the model	Average test AUC	Average training AUC	AUC p-value	AUC Z score
Vespertilionidae	*Myotis welwitschii*	2	land use/land cover	49.9	Precipitation of warmest quarter	50.1		0.84	0.90	0.001	3.29
Rhinolophidae	*Rhinolophus capensis*	3	Biome	30.5	precipitation of coldest quarter	64.1	geology	0.92	0.96	0.10	1.63

Table 8. Model selection for *Epomophorus wahlbergi* based on average AUC (n = 10) scores, for test and training data, and the AUC p-values and Mann-Whitney Z scores, for the training data, associated with the comparison of each simplified model with the larger model with one added variable. The last column gives the predictor variables removed from the previous larger models starting from the full model for *Epomophorus wahlbergi*. Bold font indicates the best model selected.

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
9	0.89	0.89			
8	0.89	0.89	0.762	0.302	Maximum temperature of warmest month
7	0.89	0.89	0.545	0.605	Isothermality
6	0.94	0.89	0.473	0.72	Precipitation of driest quarter
5	0.90	0.90	0.597	0.53	Temperature seasonality
4	0.89	0.89	0.241	1.17	Biome
3	0.93	0.90	0.006	2.76	Geology
2	**0.90**	**0.90**	**0.002**	**3.10**	**Land use/Land cover**
1	0.87	0.87	0.0002	3.74	Mean temperature of coldest quarter (i.e. with only annual precipitation)

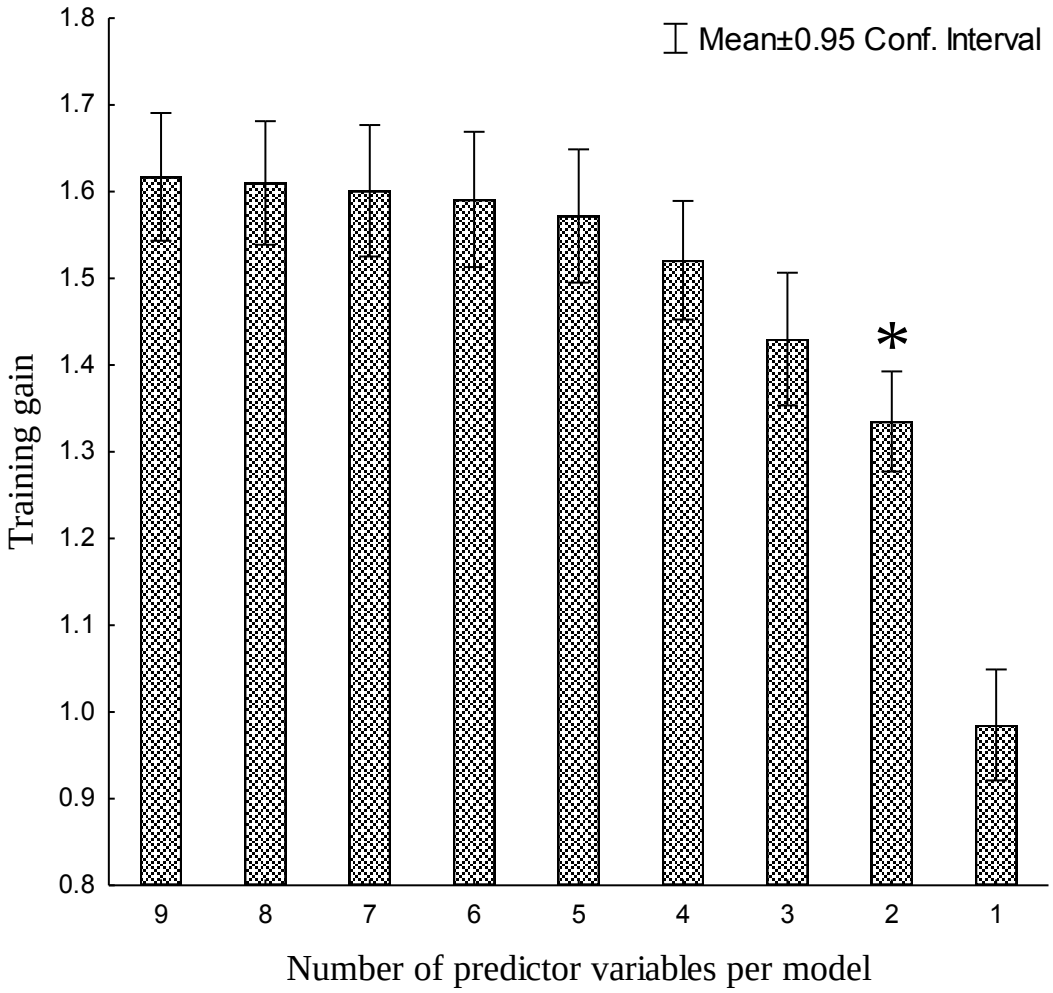

Figure 5. Values for the training gain averaged across the 10 random partitions of the presence records for *Epomophorus wahlbergi*. The model with an asterisk (*) is the one selected as the best model, i.e., the average training gain is significantly different from the models with the fewest variables but not significantly different from the models with more variables.

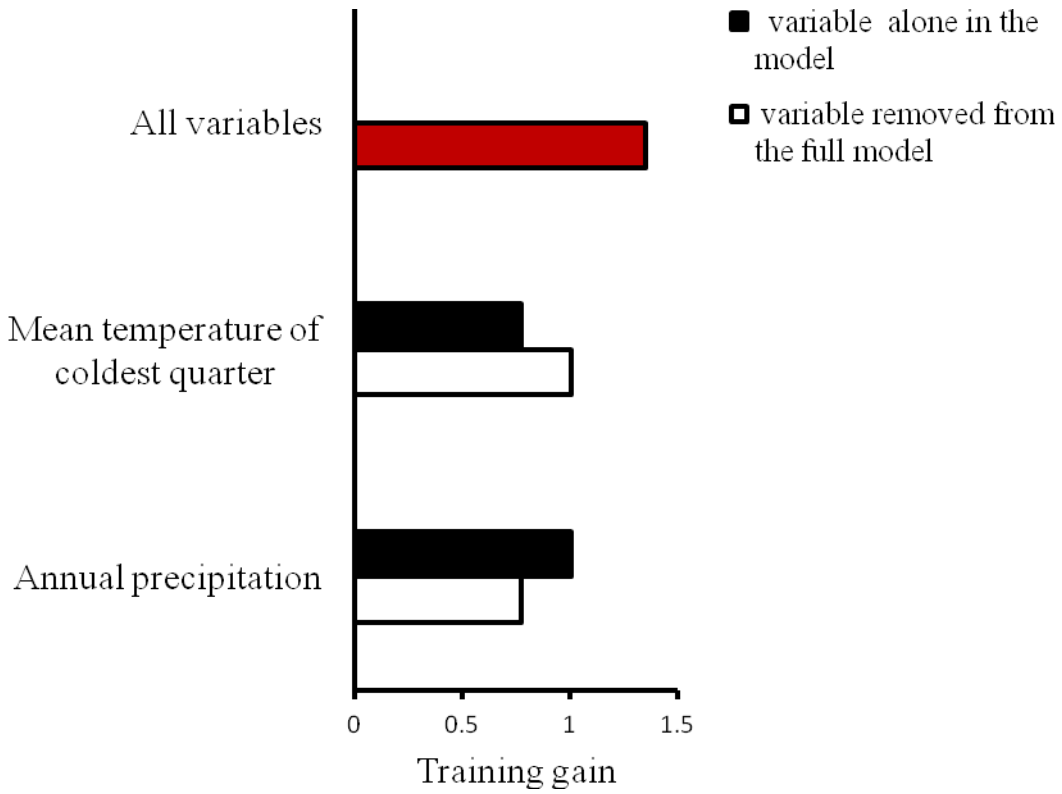

Figure 6. Jackknife test of variable importance in the final model for *Epomophorus wahlbergi*. The longer the black bar, the better the variable contribution to the model gain when the variable is used alone. The shorter the white bar, the more reduction in model gain when the variable is omitted from the full model.

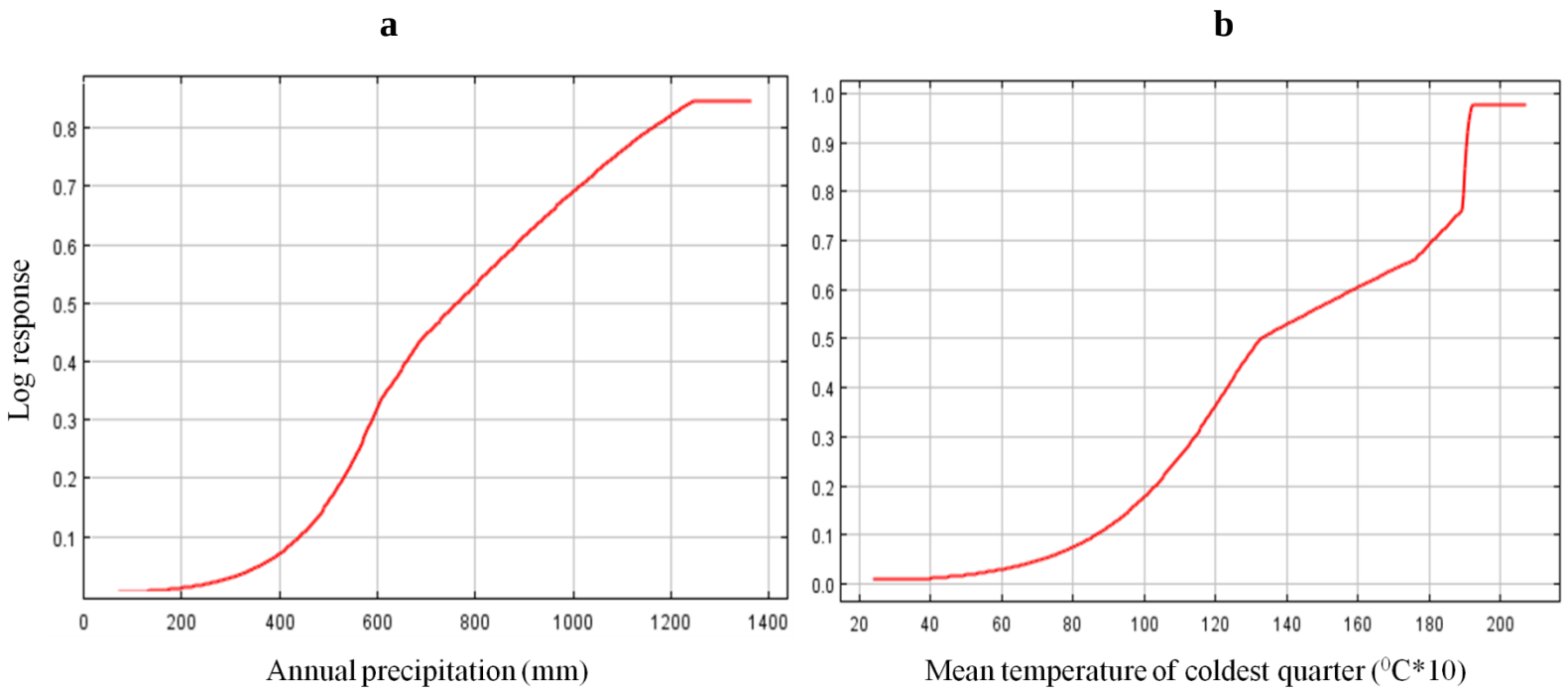

Figure 7. The log response of *Epomophorus wahlbergi* to [a] annual precipitation and [b] mean temperature of the coldest quarter when all locality records were used to build the final model.

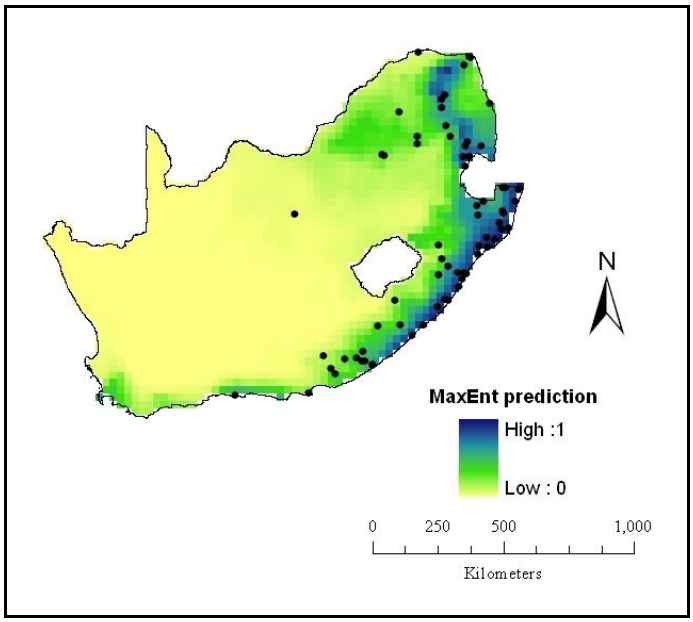

Figure 8. The probability of occurrence for *Epomophorus wahlbergi* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate the locality records used for modelling the species. Variables used in the final model include annual precipitation (the strongest predictor) and mean temperature of the coldest quarter.

Below a short description of the models for each of the 36 remaining species were provided without a detailed description of the procedures used to select the best models. This was done so to avoid unnecessary repetition. However, the same procedures were followed as for *Epomophorus wahlbergi* above. Here too the species were grouped by the variable found to have the most influence on their distributions, continuing with precipitation.

3.1.1.1.2 *Rhinolophus clivosus*

The other two species, besides *Epomophorus wahlbergi*, that responded mainly to annual

precipitation are *Rhinolophus clivosus* and *Pipistrellus hesperidus* (Table 5). Nine predictor variables were considered for modelling the distribution of *Rhinolophus clivosus*, using all 152 presence records for this species and selected a two-variable model (seeAppendices 1a, 2a, 3a) containing annual precipitation and geology (Table 5).

The final two-variable model for Rhinolophus clivosus

The log response curves (Appendix 4a) for *Rhinolophus clivosus* suggested that an annual precipitation of 50mm or less limits its distribution and that an annual precipitation of approximately 1,250mm appears to be advantageous (see Appendix 4a). The log response curve demonstrated that six geological features have a substantial positive influence (i.e., log response ≥0.5 (Appendix 4b) on *Rhinolophus clivosus*. These included: Okiep, Bushmanland, Korannaland, Geelfloer (14); Nama, Vanrhynsdorp (15); Bokkeveld (23); Barberton, Murchison, Giyani, Beit Bridge (2); Malmesbury, Kango, Gariep (24); and Table Mountain (25) (Appendix 4b). However, the greatest influence for geological features was Okiep, Bushmanland, Korannaland, Geelfloer (14) (see Appendix 4b). In contrast, the response curve illustrated that six geological features have a considerable negative influence (i.e., log response ≤ -0.5) on *Rhinolophus clivosus*. These included Kalahari (6); Rustenburg, Lebowa, Rashoop (9); Ventersdorp (11); Ecca (12); Adelaide (16); and Tarkastad (19) (Appendix 4b). However, the geological subcategory with the most negative influence on the distribution of *Rhinolophus clivosus* was Ventersdorp (11) (log reponse < -1.0) (see Appendix 4b).

Probability of occurrence map for Rhinolophus clivosus

A high probability of occurrences for this species was predicted throughout South Africa (see Figure 8). However, the central parts of the Northern Cape Province dominated by the Nama-Karoo biome, and the Northern parts of the Northern Cape Province (Kalahari region of the Savannah biome) showed a low probability of occurrence for this species.

3.1.1.1.3 *Pipistrellus hesperidus*

Ten predictor variables were examined for modelling the distribution of *Pipistrellus hesperidus* using all 37 presence records for this species. He selected a two-variable model (see Appendices

1b, 2b, 3b), which included the annual precipitation and land use/land cover (see Table 5).

The final two-variable model for Pipistrellus hesperidus

The log response curves for *Pipistrellus hesperidus* implied that its distribution is limited by an annual precipitation of about 50mm or less (see Appendix 4c). Furthermore, annual precipitation of approximately 1,250mm appeared to be the best for this species (see Appendix 4c). The log response curve illustrated that five land use/land cover types exert a sizeable positive influence (i.e., log response ≥0.5) on *Pipistrellus hesperidus*. These included: cultivated: temporary commercial–irrigated (1); thickets bushland (5); forest plantations (10); cultivated: temporary semi-commercial/subsistence-dryland (27); and cultivated: permanent commercial –sugarcane (32) (see Appendix 4d). However, the highest positive land use/land cover influence on the distribution of *Pipistrellus hesperidus* was cultivated: permanent commercial – sugarcane (32) (see Appendix 4d). In contrast, the only land use/land cover subcategory that negatively influenced the distribution of *Pipistrellus hesperidus* was unimproved grassland (6) (see Appendix 4d).

Probability of occurrence map for Pipistrellus hesperidus

The MaxEnt probability of occurrence map *for Pipistrellus hesperidus* is displayed in Figure 9. Areas with a high probability of occurrence for this species included the eastern parts of South Africa from the Albany Thicket biome near Port Elizabeth northwards throughout KwaZulu-Natal along the Indian Ocean Coastal Belt region. Additionally, the mountain and escarpment grassland in the Mpumalanga and Limpopo provinces also displayed a high probability of occurrence for *Pipistrellus hesperidus*.

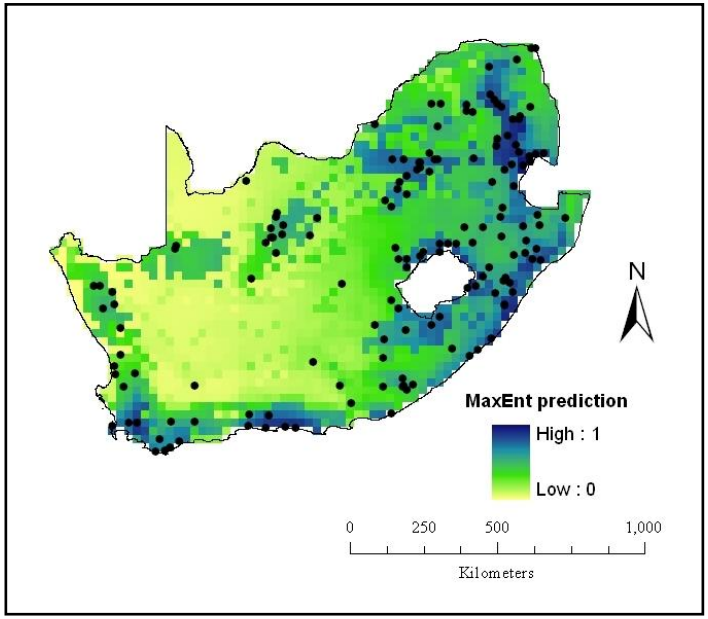

Figure 9. The probability of occurrence for *Rhinolophus clivosus* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include annual precipitation (the strongest predictor) and geology.

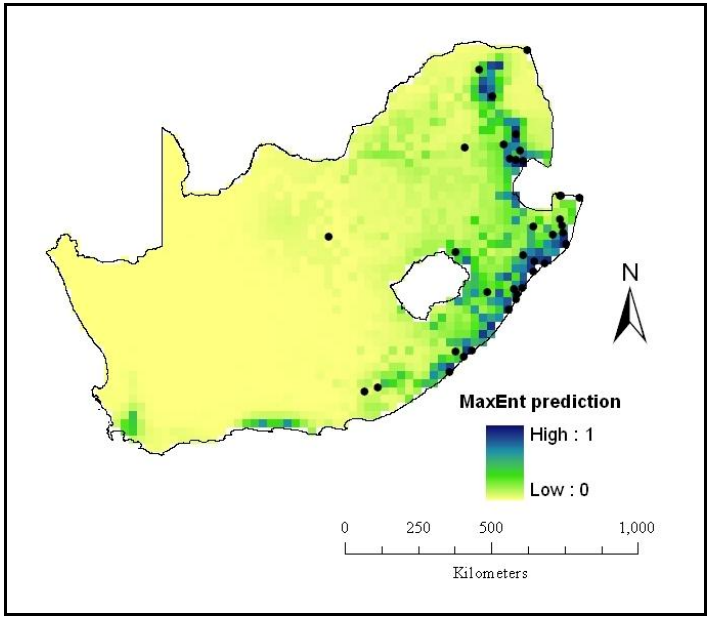

Figure 10. The probability of occurrence for *Pipistrellus hesperidus* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include annual precipitation (the strongest predictor) and land use/land cover.

3.1.1.2 Models for the four South African bat species limited by precipitation seasonality

3.1.1.2.1 *Eidolon helvum*

Twelve predictor variables were evaluated for modelling the distribution of *Eidolon helvum* using all 21 presence records. He identified a two-variable model (see Appendices 1c, 2c, 3c), which included precipitation seasonality and the precipitation of the warmest quarter (see Table 5).

The final two-variable model for Eidolon helvum

The log response curve (see Appendix 4e) suggested that the distribution of *Eidolon helvum* is limited by precipitation seasonality of between 90 and 100 percent. Moreover, precipitation seasonality of about 60 to 70 percent appears to be vital for this species. Similarly, the log response curve for precipitation in the warmest quarter (see Appendix 4f) for *Eidolon helvum* suggested that precipitation in the warmest quarter greater than 180mm was favourable for this species while that below 600mm limited the distribution of this species.

Probability of occurrence map for Eidolon helvum

A high probability of occurrence for this species exclusively included the Grassland biome of South Africa (see Figure 11). The highest probability of occurrences was predicted in the central plateau in the Free State Province of South Africa. Further, the north-east of the Eastern Cape Province on the border with Lesotho also revealed a high probability of occurrence for this species as did parts of the North-West Province along the Botswana border.

3.1.1.2.2 *Mops midas*

Nine predictor variables were assessed for modelling the distribution of *Mops midas* using all 12 presence records. He considered a two-variable model (see Appendices 1d, 2d, 3d) comprising precipitation seasonality and temperature seasonality (see Table 5).

The final two-variable model for Mops midas

The response curve for *Mops midas* (see Appendix 4g) explained that the value for precipitation seasonality which limits the distribution of this species is about 10 percent. Moreover, precipitation seasonality of about 90 to 100 percent appears to be crucial for this species. Similarly, temperature seasonality of less than 15 percent throughout the year restricts the distribution of *Mops midas* (see Appendix 4h).

Probability of occurrence map for Mops midas

Mops midas exhibited a high probability of occurrence only in the Savannah biome of South Africa (see Figure 11). The highest probability of occurrences was predicted to be in the Mopane veld region in the Limpopo Province of South Africa. This species also had a moderate probability of occurrence along the west coast of South Africa in the Succulent Karoo Biome (see Figure 12).

3.1.1.2.3 *Pipistrellus rusticus*

Seven predictor variables were tested for the distribution of *Pipistrellus rusticus* using all 33 presence records for this species. He documented a three-variable model (see Appendices 1e, 2e, 3e) which consisted of precipitation seasonality, land use/land cover and geology (see Table 5).

The final three-variable model for Pipistrellus rusticus

The log response curve for the precipitation seasonality for *Pipistrellus rusticus* (see Appendix 4i) indicated that an annual precipitation seasonality of about 10 percent limits the distribution of this species and precipitation seasonality of about 90 to 100 percent would be important for this species.

Six land use/land cover types have a positive influence on *Pipistrellus rusticus* (see Appendix 4j). These included: thickets and bushland (5); forest plantations (10); barren rock (12); urban/built-up land: residential (13); forest and woodland (17); and degraded: forest and woodland (32) (see Appendix 4j). However, the greatest influence for land use/land cover types was barren rock (12), which yielded a log response of 2.5. Only one land use/land cover

subcategory, unimproved grassland (6), revealed a negative influence on *Pipistrellus rusticus* (see Appendix 4j).

The third most limiting environmental variable for *Pipistrellus rusticus* was geology (see Appendix 4k). The log response curve illustrated that eight geological features have a positive influence on *Pipistrellus rusticus*. These included: Beaufort (1); Barberton, Murchison, Giyani, Beit Bridge (2); Suurberg, Drakensberg, Lebombo (3); Waterberg, Soutpansberg, Orange River (5); Meinhardskraal Granite, Sandriver Geinss, etcetera (7); Dwyka (8); Rustenburg, Lebowa, Rashoop (9); and Transvaal, Rooiberg, Griqualand-West (10) (see Appendix 4k). Nevertheless, the greatest influence for geological features was Beaufort (1), which indicated a log response of 2.0.

Probability of occurrence map for Pipistrellus rusticus

The highest probability of occurrence for this species was exclusively in the Savannah biome of South Africa (Figure 13). Within this biome the highest probability of occurrence was predicted to be in the Mopane veld, sweet and mixed bushveld, and the mountain or sour bushfeld regions in the Limpopo Province of South Africa. The Klipfontein area in Bushmanland, part of the Savannah biome in the Northern Cape Province, also illustrated a high probability of occurrence for this species. Furthermore, there were certain areas at the extreme east of the Augrabies and Kgalagadi National parks that indicated a moderate but patchy probability of occurrence where there were no locality points for *Pipistrellus rusticus.*

3.1.1.2.4 *Rhinolophus hildebrandtii*

Seven predictor variables were considered for modelling the distribution of *Rhinolophus hildebrandtii* based on all 14 presence records for this species. He selected a two-variable model (see Appendices 1f, 2f, 3f) which included precipitation seasonality and geology (43%) (see Table 5).

The two-variable model for Rhinolophus hildebrandtii

The log response for *Rhinolophus hildebrandtii* for precipitation seasonality (see Appendix 4l)

suggested that the distribution of this species is limited by a precipitation seasonality of about 10 percent. Conversely, a precipitation seasonality of approximately 90 to 100 percent is predicted to be favorable for this species (see Appendix 4l).

The log response curve for geology (see Appendix 4m) showed that five geological features positively influence *Rhinolophus hildebrandtii* (see Appendix 4m). These included: Barberton, Murchison, Giyani, Beit Bridge (2); Suurberg, Drakensberg, Lebombo (3); Waterberg, Southpansberg, Orange River (5); Rusternburg, Lebowa, Rashoop (9); and Transvaal, Rooiberg, Griqualand-West (10) (see Appendix 4m). Nevertheless, the greatest influence for geological features was Transvaal, Rooiberg, Griqualand-West (10), which yielded a log response of 2.5 (see Appendix 4m).

Probability of occurrence map for Rhinolophus hildebrandtii

Areas with a high probability of occurrence for this species comprised the Savannah biome of South Africa (see Figure 14). The highest probability of occurrences within this biome was predicted to fall in the Mopane veld, sweet and mixed bushveld as well as the mountain or sour bushfeld regions in the Limpopo Province of South Africa. Some parts of Bushmanland in the Savannah biome in the Northern Cape Province also revealed a considerable probability of occurrence for this species. Furthermore, there were certain areas in the Kgalagadi Transfrontier Park that demonstrated a moderate but patchy probability of occurrence where there were no locality points for *Rhinolophus hildebrandtii*.

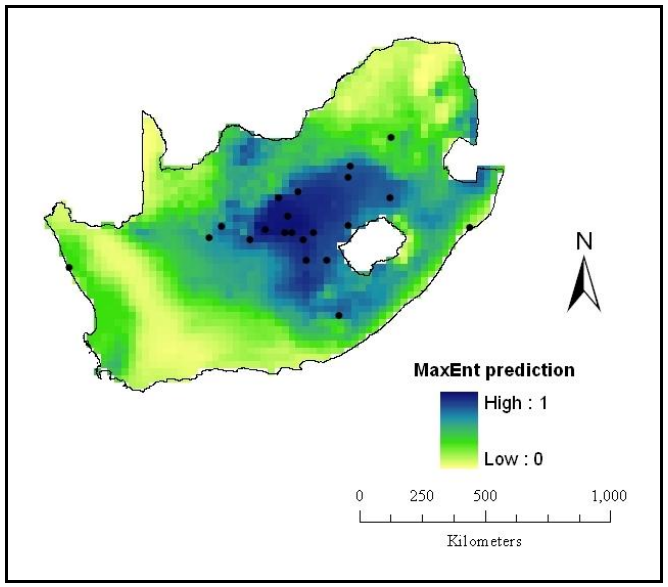

Figure 11. The probability of occurrence for *Eidolon helvum* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include precipitation seasonality (the strongest predictor) and precipitation of the warmest quarter.

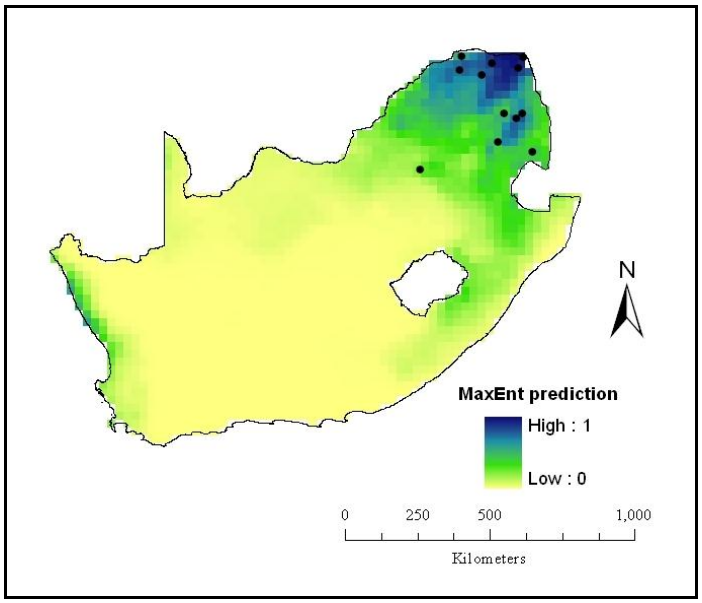

Figure 12. The probability of occurrence for *Mops midas* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include precipitation seasonality (the strongest predictor) and temperature seasonality.

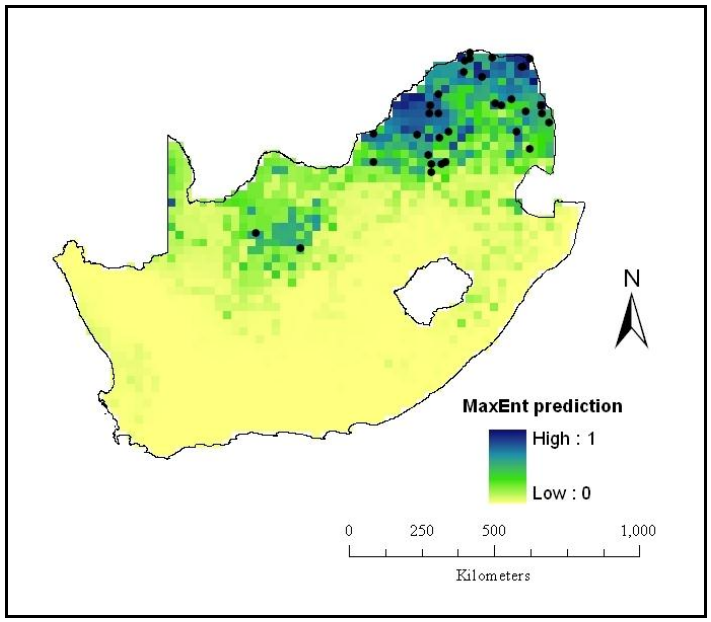

Figure 13. The probability of occurrence for *Pipistrellus rusticus* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include precipitation seasonality (the strongest predictor), geology and land use/land cover.

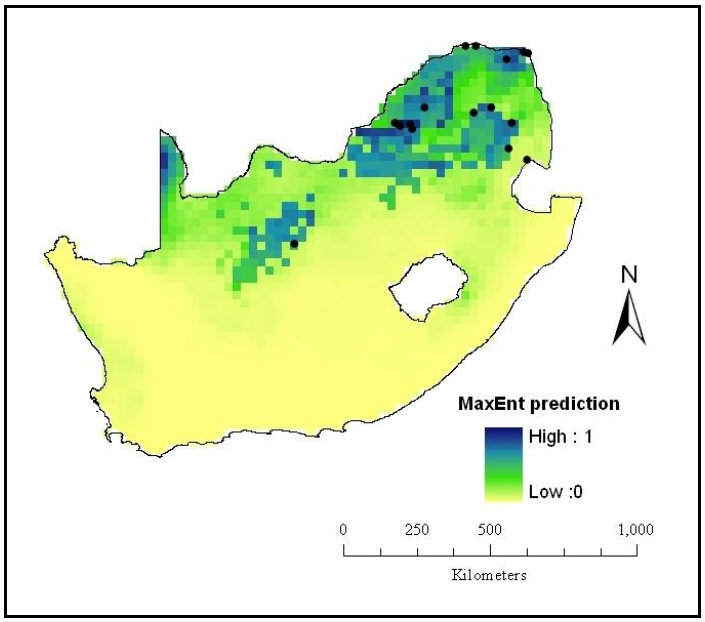

Figure 14. The probability of occurrence for *Rhinolophus hildebrandtii* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include precipitation seasonality (the strongest predictor) and geology.

3.1.1.3 Models for the Two South African Bat Species Limited by Precipitation in the Warmest Quarter

3.1.1.3.1 *Rhinolophus blasii*

Seven predictor variables were analysed for modelling the distribution of *Rhinolophus blasii* by allocating all 13 presence records for this species (see Table 5). He determined a two-variable model (see Appendices 1g, 2g, 3g), which contained the precipitation of the warmest quarter and geology (see Table 5).

The two-variable model for Rhinolophus blasii

The response curve for the precipitation in the warmest quarter for *Rhinolophus blasii* (Appendix 4n) demonstrated that precipitation of approximately 600 mm is beneficial to this species.

Similarly, the log response curve (see Appendix 4o) illustrated that five geological features positively influence *Rhinolophus blasii*. These included: Barberton, Murchison, Giyani, Beit Bridge (2); Suurberg, Drakensberg, Lebombo (3); Meinhardskraal Granite, Sandriver Geinss, etcetera (7); Dwyka (8); and Transvaal, Rooiberg, Griqualand-West (10) (see Appendix 4o). However, the greatest influence for geological features was Barberton, Murchison, Giyani, and Beit Bridge (2), which yielded a log response of 1.8. The second highest contribution was from Transvaal, Rooiberg, Griqualand-West (10) which yielded a log response of 1.5.

Probability of occurrence map for Rhinolophus blasii

A high probability of occurrence for this species was predicted in the lowveld region of the Savannah biome in the Limpopo Province of South Africa (see Figure 15). Additionally, the sweet and mixed bushveld region of the Savannah biome in the North West Province also demonstrated a substantial probability of occurrence for this species. In contrast, certain areas in the Kalahari region indicated a moderate probability of occurrence where there were no locality points for *Rhinolophus blasii.*

3.1.1.3.2 *Rhinolophus simulator*

Seven predictor variables were used for modelling the distribution of *Rhinolophus simulator* based on all 49 presence records for this species. He decided on a two-variable model (see Appendices 1h, 2h, 3h), which incorporated the precipitation of the warmest quarter and the geology (see Table 5).

The two-variable model for Rhinolophus simulator

The log response curve for precipitation in the warmest quarter for *Rhinolophus simulator* (see Appendix 4p) confirmed that precipitation of approximately 600 mm appears to be advantageous for this species. There were ten geological features that had a positive influence on *Rhinolophus simulator*, while only one exerted a negative influence on this species (see Appendix 4q). Geological features with a positive influence included: Beaufort (1); Barberton, Murchison, Giyani, Beit Bridge (2); Suurberg, Drakensberg, Lebombo (3); Zululand, Malvernia (4); Meinhardskraal Granite, Sandriver Geinss, etcetera (7); Rusternburg, Lebowa, Rashoop (9); Transvaal, Rooiberg, Griqualand-West (10); Adelaide (16); Natal (17); and Tugela, Mapumulo (22) (see Appendix 4q). Nevertheless, the greatest influence for geological features was Zululand, Malvernia (4), which yielded a log response of 3.4. The second greatest influence was Tugela, Mapumulo (22), which had a log response of 2.25. On the other hand, the only geological subcategory with a negative influence (Ecca (12)), had a log response of -0.25.

Probability of occurrence map for Rhinolophus simulator

Areas with a high probability of occurrence for this species included the Savannah biome of South Africa (see Figure 16). Within this biome, the highest probability of occurrences was predicted to fall in the lowveld region of the Limpopo and KwaZulu-Natal Provinces of South Africa. The sweet and mixed bushveld region of the Savannah biome in the North West Province also indicated a moderate probability of occurrence for this species.

3.1.1.4 A model for One South African Bat Species Limited by Precipitation in the Coldest Quarter

3.1.1.4.1 *Neoromicia melckorum*

Thirteen predictor variables were used for modelling the distribution of *Neoromicia melckorum* including all 24 presence records for this species. He considered a two-variable model (see Appendices 1i, 2i, 3i) which comprised precipitation in the coldest quarter and precipitation in the warmest quarter (see Table 5).

The final two-variable model for Neoromicia melckorum

The response curve for precitpiation in the coldest quarter for *Neoromicia melckorum* (see Appendix 4r) suggested that precipitation in the coldest quarter of between 150 and 450 mm should be beneficial for this species. Similarly, precipitation in the warmest quarter of <50 mm would limit the distribution of this species (see Appendix 4s).

Probability of occurrence map for Neoromicia melckorum

Areas with a high probability of occurrence for *Neoromicia melckorum* included the Fynbos and the Succulent Karoo biomes of South Africa (Figure 17). The highest probability of occurrences within these biomes was predicted to fall in the Fynbos and Renosterveld region in the Western Cape Province of South Africa.

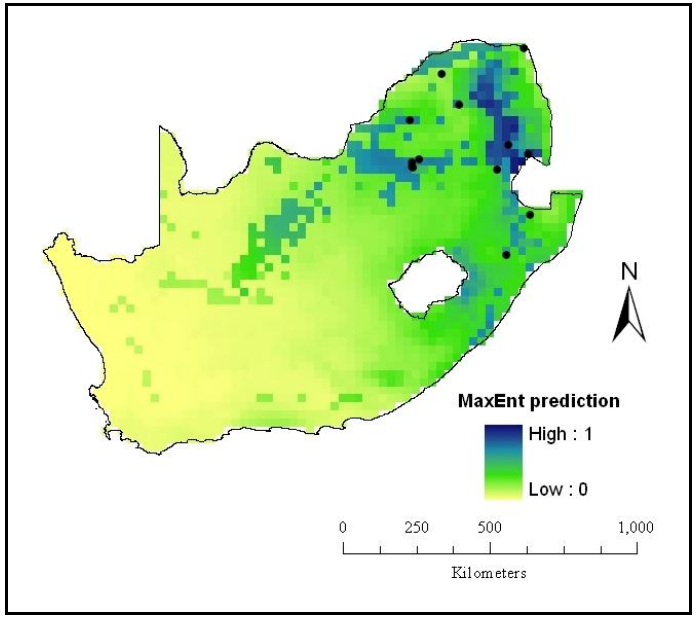

Figure 15. The probability of occurrence for *Rhinolophus blasii* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include precipitation of the warmest quarter (the strongest predictor) and geology.

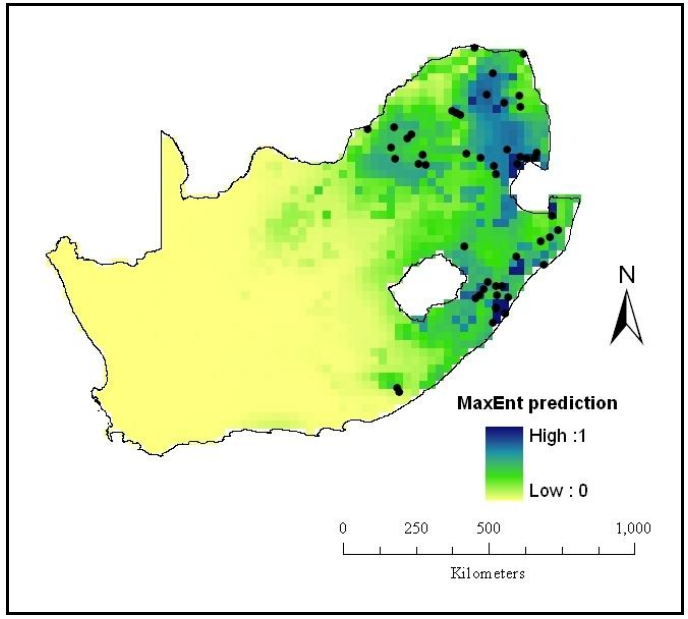

Figure 16. The probability of occurrence for *Rhinolophus simulator* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include precipitation of the warmest quarter (the strongest predictor) and geology.

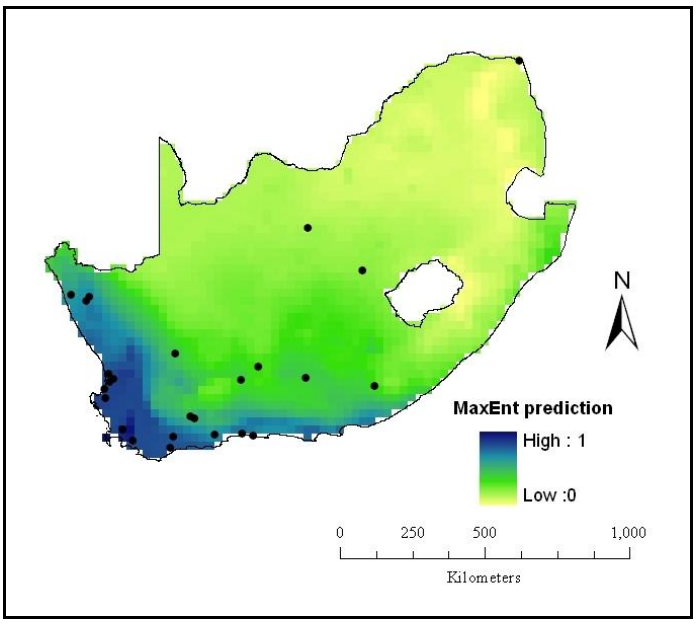

Figure 17. The probability of occurrence for *Neoromicia melckorum* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include precipitation of the coldest quarter (the strongest predictor) and precipitation of the warmest quarter.

3.1.2 Models for the 12 South African Bat Species Limited by Temperature Variables

3.1.2.1 Models for the Six South African Bat Species Limited by Mean Temperature in the Coldest Quarter

3.1.2.1.1 *Scotophilus dinganii*

Eight predictor variables were analysed when modelling the distribution of *Scotophilus dinganii* using all 86 presence records for this species. He indentified a three-variable model (see Appendices 1j, 2j, 3j) which included, in order of importance, the mean temperature of the coldest quarter, precipitation in the warmest quarter and land use/land cover (see Table 6).

The final three-variable model for Scotophilus dinganii

A mean temperature of the coldest quarter of about 19°C (see Appendix 4t) and precipitation in the warmest quarter of between 300 and 600 mm (see Appendix 4u) would be favourable for this species. It appeared that six land use/land cover types had a positive influence on *Scotophilus dinganii*. These included: cultivated: permanent commercial – irrigated land (3); thickets bushland (5); barren rock (12); forest and woodland (17); improved grassland (23); and forest (26). However, the greatest influence for land use/land cover types was improved grassland (23), for which a log response of 3.9 was revealed (see Appendix 4v). Nevertheless, degraded: thickets and bushland, etcetera (9), displayed a negative log response of -0.51 (see Appendix 4v).

Probability of occurrence map for Scotophilus dinganii

Areas with a high probability of occurrence for this species included the lowveld region of the Savannah biome that extends from Port Elizabeth northwards along the coast to the junction of the Mozambican, Zimbabwean and South African borders. Furthermore, a high probability of occurrence for this species was exhibited in the Mopane veld as well as the sweet and mixed bushveld regions of the Savannah biome located in the Limpopo Province (Figure 18).

3.1.2.1.2 *Scotophilus viridis*

Six predictor variables were used for modelling the distribution of *Scotophilus viridis* by employing all 17 presence records for this species. He distinguished a two-variable model (see Appendices 1k, 2k, 3k) comprising the mean temperature of the coldest quarter and geology (see Table 6).

The final two-variable model for Scotophilus viridis

A mean temperature of about 19°C for the coldest quarter would favour the occurrence of this species while a mean temperature of <13°C in the coldest quarter could constitute a limiting factor for this species (see Appendix 4w). It transpired that four geological features exerted a positive influence on *Scotophilus viridis* (see Appendix 4x). These included: Beaufort (1); Kalahari (6); Transvaal, Rooiberg, Griqualand-West (10); and Ecca (12) (see Appendix 4x). Nonetheless, the greatest influence for geological features was Transvaal, Rooiberg, and Griqualand-West (10), which yielded a log response of 2.3.

Probability of occurrence map for Scotophilus viridis

Areas with a high probability of occurrence for this species included the lowveld region of the Savannah biome that extends from St Lucia northwards along the coast to the Swaziland border. Furthermore, a high probability of occurrence for this species was also predicted for the Mopane veld region of the Savannah biome that included the north and northeastern parts of the Limpopo Province as well as the eastern parts of the Mpumalanga Province.

3.1.2.1.3 *Chaerephon pumilus*

Ten predictor variables were evaluated for the distribution of *Chaerephon pumilus* using all 56 presence records for this species. He described a two-variable model (see Appendices 1l, 2l, 3l), which consisted of the mean temperature of the coldest quarter and the precipitation of the warmest quarter (see Table 6).

The final two-variable model for Chaerephon pumilus

The distribution of *Chaerephon pumilus* appeared to be limited by a mean temperature of the coldest quarter of <6°C (see Appendix 4y) while a mean temperature of the coldest quarter of about 18°C should be favourable for this species (see Appendix 4y). Furthermore, the distribution of this species was also limited by a precipitation of <100 mm in the warmest quarter and favoured by a precipitation of about 600mm in the warmest quarter (Appendix 4z).

Probability of occurrence map for Chaerephon pumilus

A high probability of occurrence for this species occurred mostly in the lowveld and Mopane veld regions of the Savannah biome of South Africa (see Figure 20). In the south, the area of high probability of occurrence extends from about Durban northwards along the coast to the Swaziland border. In the north, the area of high probability of occurrence is located in the northeast and northern parts of the Limpopo Province.

3.1.2.1.4 *Mops condylurus*

Nine predictor variables were examined for modelling the distribution of *Mops condylurus* using all 30 presence records for this species. He uncovered a two-variable model (see Appendices 1m, 2m, 3m), which included a mean temperature of the coldest quarter and geology (see Table 6).

The final two-variable model for Mops condylurus

A mean temperature of the coldest quarter of <4°C appears to limit the distribution of *Mops condylurus*. Conversly, a mean temperature of the coldest quarter of about 19°C appears to favour this species (see Appendix 4aa). The log response curve for geological features illustrated that eight geological features had a positive influence on the distribution of *Mops condylurus*. These included: Beaufort (1); Suurberg, Drakensberg, Lebombo (3); Kalahari (6); Transvaal, Rooiberg, Griqualand-West (10); Ecca (12); Adelaide (16); Natal (17); and Tugela, Mapumulo (22). However, the areas with the greatest influence by geological features were: Ecca (12) which had a log response of 1.8; Natal (17), with a log response of 1.7; and Transvaal, Rooiberg, Griqualand-West (10) with a log response of 1.65 (see Appendix 4ab).

Probability of occurrence map for Mops condylurus

Areas with a high probability of occurrence for this species occurred mostly in the lowveld and Mopane veld regions of the Savannah biome of South Africa (see Figure 21). These areas extend from Durban northwards along the coast to the Swaziland border and continue to the northeast and northern parts of the Limpopo Province.

3.1.2.1.5 *Hipposideros caffer*

Nine predictor variables and all 56 presence records were used for modelling the distribution of *Hipposideros caffer.* He selected a three-variable model (see Appendices 1n, 2n, 3n) comprising the mean temperature of the coldest quarter, precipitation in the warmest quarter, and geology (see Table 6).

The final three-variable model for Hipposideros caffer

The distribution of *Hipposideros caffer* is limited by a mean temperature of <6°C and favoured by a mean temperature of 19°C in the coldest quarter (see Appendix 4ac). Similarly, it is limited by a precipitation in the warmest quarter of <125 mm and favoured by a precipitation of 600 mm or more (see Appendix 4ad). The log response curve confirmed that six geological features exert a positive influence, while three have a negative influence on the distribution of *Hipposideros caffer* (see Appendix 4ae). Geological features exerting a positive influence included: Beaufort (1); Suurberg, Drakensberg, Lebombo (3); Zululand, Malvernia (4); Transvaal, Rooiberg, Griqualand-West (10); Ecca (12); Natal (17); and Tugela, Mapumulo (22). However, the areas in which the geological features exerted the greatest influence were: Zululand, Malvernia (4), which indicated a log response of 1.75; and Tugela, Mapumulo (22) which yielded a log response of 1.0 (see Appendix 4ae). Geological features with a negative influence included: Waterberg, Southpansberg, Orange River (5); Kalahari (6); and Adelaide (16) (see Appendix 4ae). However, the most negatively influential geological sub-categories were: Waterberg, Southpansberg, Orange River (5), which had a log response of -1.5; and Kalahari (6), which had a log response of -1.0.

Probability of occurrence map for Hipposideros caffer

Areas with a high probability of occurrence for this species were in the lowveld, Mopane veld

and the sweet and mixed bushveld regions of the Savannah biome of South Africa (see Figure 22). These areas extend from near Port St John's northwards along the coast to the Swaziland border and continue towards the eastern parts of Mpumalanga as well as the north-east and northern parts of the Limpopo Province.

3.1.2.1.6 *Epomophorus crypturus*

Nine predictor variables were evaluated using all 17 presence records for the distribution of *Epomophorus crypturus*. A two-variable model was selected (see Appendices 1o, 2o, 3o) incorporating the mean temperature of the coldest quarter and land use/land cover (see Table 6).

The final two-variable model for Epomophorus crypturus

A mean temperature of <4°C in the coldest quarter appears to limit the distribution of *Epomophorus crypturus* and a mean temperature in the coldest quarter of about 19°C appears to be crucial for the occurrence of this species (see Appendix 4af). The second most limiting environmental variable for *Epomophorus crypturus* after the mean temperature of the coldest quarter was land use/land cover. The log response curve demonstrated that six land use/land cover types have a positive influence on *Epomophorus crypturus* (see Appendix 4ag). These included: thickets bushland (5); forest plantations (10); urban/built-up land: residential (13); forest and woodland (17); degraded: forest and woodland (30); and cultivated: permanent commercial: sugarcane (32) (see Appendix 4ag). However, of the land use/land cover types, those that exerted the greatest influence were: forest plantations (10), which had a log response of 0.8; forest and woodland (17) with a log response of 0.58; and cultivated: permanent commercial: sugarcane (32) with a log response of 0.55.

Probability of occurrence map for Epomophorus crypturus

Areas with a high probability of occurrence for this species were located in the Mopane veld region of the Savannah biome of South Africa. This area includes mainly the eastern parts of the Mpumalanga Province (see Figure 23).

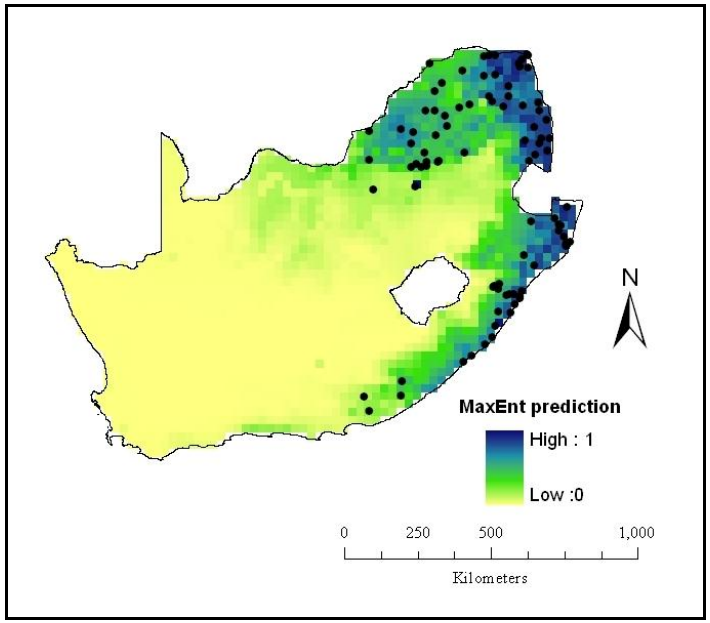

Figure 18. The probability of occurrence for *Scotophilus dinganii* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and land use/land cover.

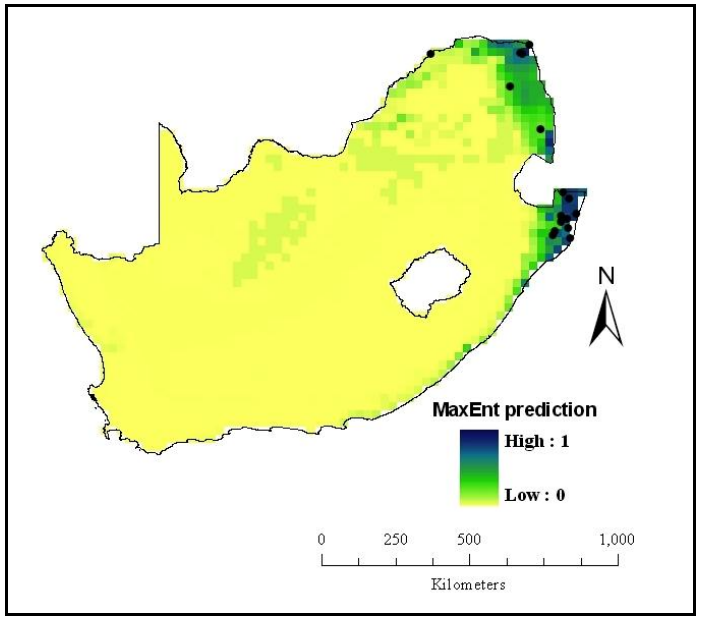

Figure 19. The probability of occurrence for *Scotophilus viridis* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and geology.

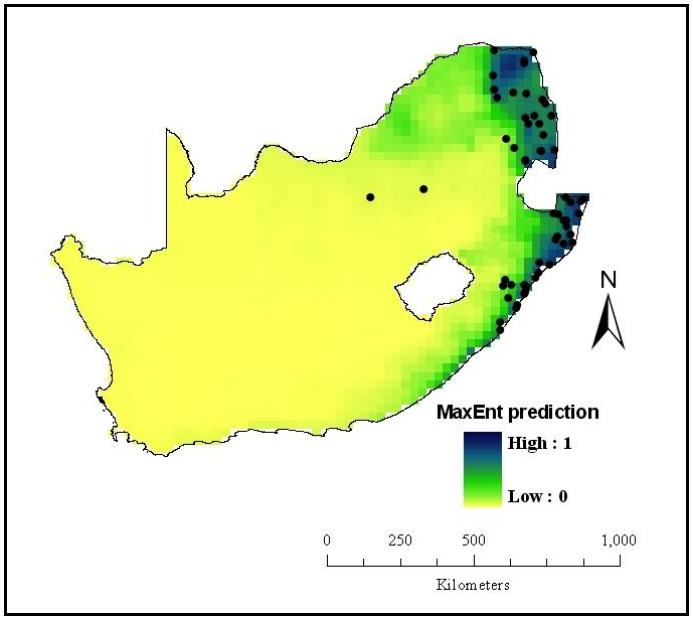

Figure 20. The probability of occurrence for *Chaerephon pumilus* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and precipitation of the warmest quarter.

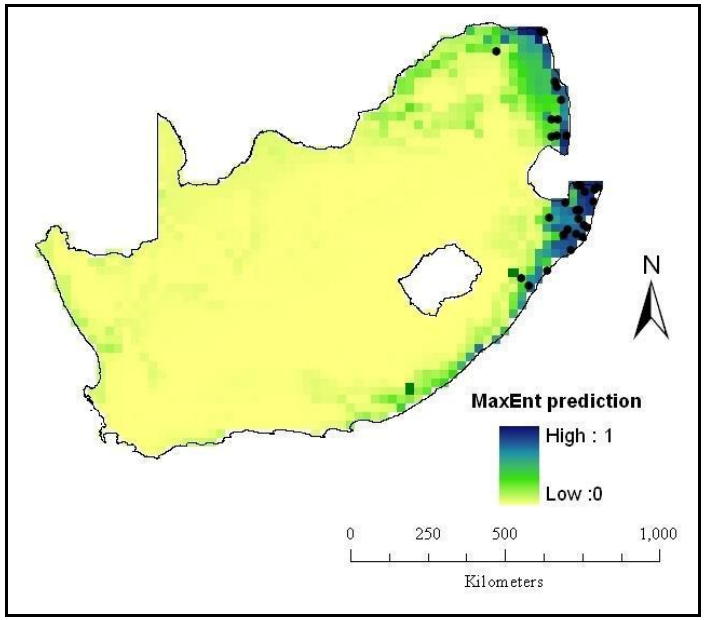

Figure 21. The probability of occurrence for *Mops condylurus* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and geology.

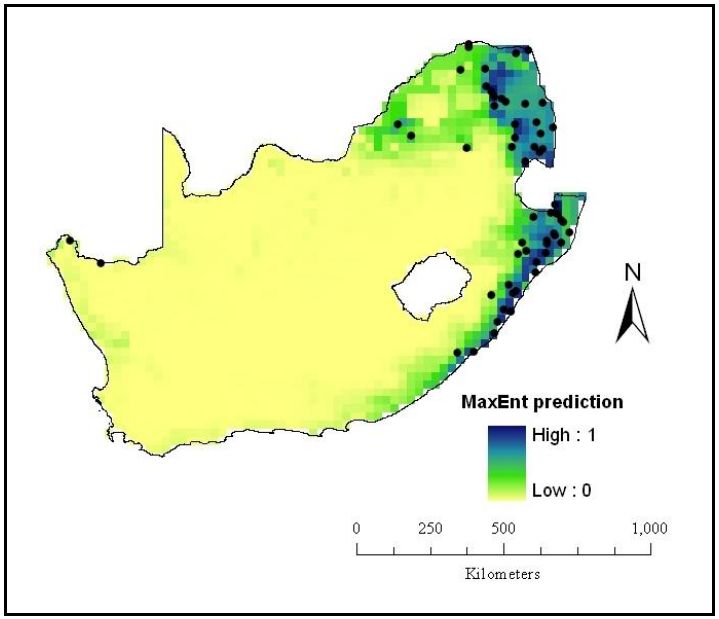

Figure 22. The probability of occurrence for *Hipposideros caffer* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

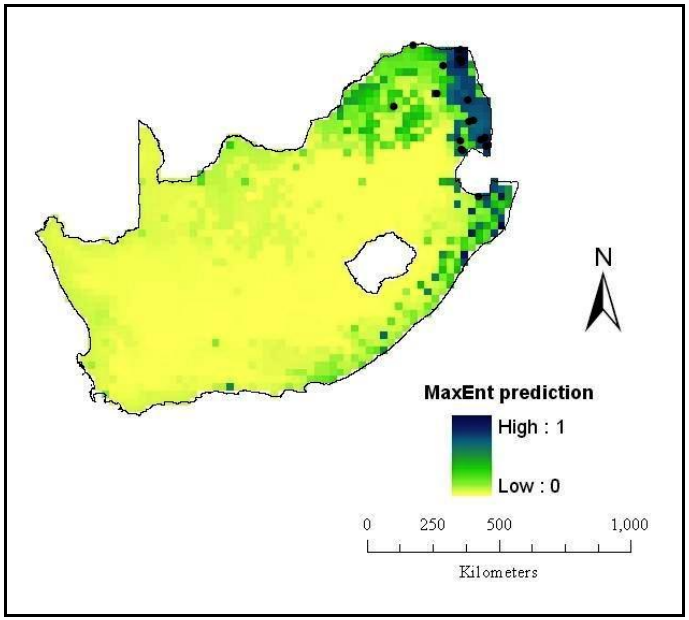

Figure 23. The probability of occurrence for *Epomophorus crypturus* in South Africa. The predictions (Low)-(High) show a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

3.1.2.2 Models for the Two South African Bat Species Limited by Temperature Seasonality

3.1.2.2.1 *Rhinolophus swinnyi*

Ten predictor variables and all 15 presence records were evaluated for modeling the expected distribution of *Rhinolophus swinnyi*. A two-variable model (see Appendices 1p, 2p, 3p) was uncovered incorporating temperature seasonality and geology (see Table 6).

The final two-variable model for Rhinolophus swinnyi

The MaxEnt response curve demonstrated that the log response for *Rhinolophus swinnyi* drops below zero as the temperature seasonality reaches 15 percent (see Appendix 4ah). The value of the log response curve started at zero for the lowest value of temperature seasonality (10%); then, the log response collapsed to below zero at 15 percent of temperature seasonality. As a consequence, the limiting value for the distribution of *Rhinolophus swinnyi* is restricted by a temperature seasonality of ≥15 percent and favoured by a temperature seasonality of <15 percent throughout the year.

The second most limiting environmental variable for *Rhinolophus swinnyi* after temperature seasonality was geology (see Appendix 4ai). The response curve confirmed that six geological features have a positive influence on the predicted distribution of *Rhinolophus swinnyi*. These included: Beaufort (1); Suurberg, Drakensberg, Lebombo (3); Transvaal, Rooiberg, Griqualand-West (10); Ecca (12); Adelaide (16); and Natal (17) (Appendix 4ai). However, the geological features with the greatest influence were Beaufort (1), which yielded a log response of 3.4. The geological features of Transvaal, Rooiberg, Griqualand-West (10), which had a log response of 2.4, exerted the second highest level of influence.

Probability of occurrence map for Rhinolophus swinnyi

The areas with a high probability of occurrence for this species included the lowveld region of the Savannah biome of South Africa (Figure 23). This area included the eastern part of South Africa from Port Elizabeth northwards towards the Swaziland border. Some areas in the Limpopo Province also demonstrated a moderate probability of occurrence for this

species.

3.1.2.2.2 *Kerivoula lanosa*

Ten predictor variables and all 12 presence records were assessed for the distribution of *Kerivoula lanosa.* A four-variable model (see Appendices 1q, 2q, 3q) was selected comprising temperature seasonality, geology, land use/land cover and biome (see Table 6).

The final four-variable model for Kerivoula lanosa

A temperature seasonality of ≥18 percent appeared to limit the occurrence of *Kerivoula lanosa* and a temperature seasonality of <18 percent throughout the year appeared to favour its occurrence (see Appendix 4aj). The second most limiting environmental variable for *Kerivoula lanosa* after temperature seasonality was geology (see Appendix 4ak). The response curve demonstrated that seven geological features exert a positive influence on *Kerivoula lanosa* (see Appendix 4ak). These included: Beaufort (1); Suurberg, Drakensberg, Lebombo (3); Zululand, Malvernia (4); Waterberg, Southpansberg, Orange River (5); Transvaal, Rooiberg, Griqualand-West (10); Adelaide (16); and Table Mountain (25) (Appendix 4ak). However, the greatest influence for geological features was Zululand, Malvernia (4), which indicated a log response of 3.4.

It transpired that five land use/land cover types had a positive influence on *Kerivoula lanosa* (see Appendix 4al). These included: thickets bushland (5); forest plantations (10); cultivated: temporary commercial dryland (11); degraded: unimproved grassland (16); and forest and woodland (17). However, the greatest influence for land use/land cover types was thickets bushland (5) for which a log response of 1.2 was reported. Only one biome subcategory, Albany thicket (5), had a positive influence on *Kerivoula lanosa* (see Appendix 4am).

Probability of occurrence map for Kerivoula lanosa

Areas with a high probability of occurrence for this species were located mostly in the lowveld region of the Savannah biome of South Africa (see Figure 24). These areas extend from the Swaziland border southwards towards Port Elizabeth. In addition, areas extending from East London southwards towards George also indicate a high probability of occurrence

for this species. Furthermore, some areas in the Limpopo Province show a moderate probability of occurrence for this species (see Figure 24).

3.1.2.3 Models for the Two South African Bat Species Limited by the Minimum Temperature of the Coldest Month

3.1.2.3.1 *Nycteris thebaica*

Twelve predictor variables and all 129 presence records were used to model the distribution of *Nycteris thebaica*. The best model was a three-variable model (see Appendices 1r, 2r, 3r) comprising the minimum temperature of the coldest month; land use/land use and geology (see Table 6).

The final three-variable model for Nycteris thebaica

The MaxEnt response curve illustrated that the log response for *Nycteris thebaica* reached about 3.0 when the minimum temperature of the coldest month was 12.5°C (see Appendix 4an. The value of the log response curve started at 1.5 for the lowest value of the minimum temperature of the coldest month (0°C). Afterwards, it rose gradually to 3.75 at 11°C, and subsequently dropped suddenly to a log response of 3.0 at about 12.5°C where the curve stabilised. Therefore, the minimum temperature for the coldest month of 0°C limited the occurrence of *Nycteris thebaica*. They appeared to prefer a minimum temperature for the coldest month of the year that ranges between 11 and 12.5°C.

It became apparent that eight land use/land cover types have a positive influence on *Nycteris thebaica* while three sub-categories have a negative influence on this species (see Appendix 4ao). Land use/land cover types with a positive influence included: cultivated: temporary commercial – irrigated land (1); thickets bushland (5); unimproved grassland (6); waterbodies (8); cultivated: temporary commercial dryland (11); urban/built-up land: residential (13); forest and woodland (17); and cultivated: permanent commercial – sugarcane covered land (32) (see Appendix 4ao). However, the land use/land cover types that exerted the greatest

influence were: cultivated: temporary commercial – irrigated land (1) which had a log response of 1.3; forest and woodland (17) with a log response of 1.0; as well as thickets bushland (5) and Waterbodies (8), which both yielded a log response of 0.8. In contrast, the land use/land cover types that indicated a negative influence were: degraded: thickets and bushland, etcetera (9), which had a log response of -0.35; forest plantations (10) with a log response of -0.2; and cultivated: temporary semi-commercial/subsistence-dryland (27) with a log response of -0.1 (see Appendix 4ao).

There were 11 geological features that had a positive influence on *Nycteris thebaica* and two sub-categories that had a negative influence on this species. The geological sub-categories with a positive influence included: Beaufort (1); Suurberg, Drakensberg, Lebombo (3); Transvaal, Rooiberg, Griqualand-West (10); Ecca (12); Witwatersrand, Dominion, Pongola (13); Okiep, Bushmanland, Korannaland, Geelfloer (14); Adelaide (16); Cape Granite (21); Tugela, Mapumulo (22); Bokkeveld (23); and Malmesbury, Kango, Gariep (24) (see Appendix 4ap). However, the greatest influences for geological features were: Cape Granite (21), which had a log response of 1.5; Transvaal, Rooiberg, Griqualand-West (10) with a log response of 1.0; and Tugela, Mapumulo (22) with a log response of 0.9 (see Appendix 4ap). Geological sub-categories with a negative influence were Meinhardskraal Granite, Sandriver Geinss, etcetera (7); and Witteberg (20), both with a log response of -0.3 (see Appendix 4ap).

Probability of occurrence map for Nycteris thebaica

Areas with a high probability of occurrence for *Nycteris thebaica* cover most of South Africa (see Figure 25). However, a very low probability of occurrence for this species is reported in the grassland of the central Highveld in the Grassland biome of South Africa and the Nama-Karoo biome of South Africa (see Figure 25).

3.1.2.3.2 *Neoromicia nana*

Nine predictor variables and all 52 presence records were examined for *Neoromicia nana* (see Figure 27). The best model was a three-variable model (see Appendices 1s, 2s, 3s), which consisted of the minimum temperature of the coldest month, the precipitation of the warmest quarter, and geology (see Table 6).

The final three-variable model for Neoromicia nana

A minimum temperature in the coldest month of ≥-4.0°C limited the occurrence of *Neoromicia nana*. This species appeared to prefer a minimum temperature in the coldest month of about 12.5°C (see Appendix 4aq). Precipitation in the warmest quarter of <300 mm appeared to limit the occurrence of this species whereas precipitation of about 600 mm in the warmest quarter appeared to be vital for *Neoromicia nana* (see Appendix 4ar).

There were 10 geological features that had a positive influence on *Neoromicia nana* and only one subcategory that had a negative influence on this species (see Appendix 4as). Geological features with a positive influence included: Barberton, Murchison, Giyani, Beit Bridge (2); Suurberg, Drakensberg, Lebombo (3); Zululand, Malvernia (4); Kalahari (6); Rusternburg, Lebowa, Rashoop (9);Transvaal, Rooiberg, Griqualand-West (10); Ecca (12); Witwatersrand, Dominion, Pongola (13); Natal (17); and Tugela, Mapumulo (22) (see Appendix 4as). However, the geological features with the greatest influence were: Zululand, Malvernia (4) which had a log response of 1.9; followed by Witwatersrand, Dominion, Pongola (13) with a log response of 1.1. The only geological feature that had a negative influence on *Neoromicia nana* was Adelaide (16), which had a log response of -0.4 (see Appendix 4as).

Probability of occurrence map for Neoromicia nana

Areas with a high probability of occurrence for *Neoromicia nana* covered the lowveld and the Mopane veld regions of the Savannah biome of South Africa (see Figure 27). This area extends from Port St John's in KwaZulu-Natal northwards towards the Swaziland border. The northern limit of the area of high probability of occurrence for this species occurs in the eastern parts of Mpumalanga and the north-eastern parts of the Limpopo Province.

3.1.2.4 A model for One South African Bat Species Limited by Temperature Annual Range

3.1.2.4.1 *Miniopterus fraterculus*

Eleven predictor variables were tested for the distribution of *Miniopterus fraterculus* using all 25 presence records for this species. A three-variable model (see Appendices 1t, 2t, 3t) was selected which included an annual range in temperature, land use/land cover, and geology (see Table 6).

The final three-variable model for Miniopterus fraterculus

The MaxEnt log response curve demonstrated that the log response for *Miniopterus fraterculus* reached 1.0 when the annual temperature range was 18°C (see Appendix 4at). The value of the log response curve started at zero for the lowest value of the annual temperature range (13°C); then it increased to 1.0 at 18°C where the curve started to level off and subsequently declined steeply to below zero. Hence, the limiting value for an annual range in temperature of >18°C restricted the occurrences of *Miniopterus fraterculus*. It appeared to prefer an annual range in temperature of between 13 and 18°C (see Appendix 4at).

It transpired that six land use/land cover types have a positive influence on *Miniopterus fraterculus* while only two sub-categories have a negative influence on this species (see Appendix 4au). The land use/land cover types with a positive influence included: unimproved grassland (6); forest plantations (10); cultivated: temporary commercial dryland (11); urban/built-up land: residential (13); cultivated: permanent commercial dryland (15); and forest (26) (see Appendix 4au). However, the land use/land cover types with the greatest influence were: cultivated: permanent commercial dryland (15), which had a log response of 2.4; forest (26) with a log response of 1.9; and forest plantations (10) with a log response of 1.4 (see Appendix 4au). The land use/land cover types with a negative influence were: shrubland and low fynbos (2), which had a log response of -0.8; and thickets bushland (5), which had a log response of -0.5 (see Appendix 4au).

There were 11 geological features that had a positive influence on *Miniopterus fraterculus* (see Appendix 4av). These included: Barberton, Murchison, Giyani, Beit Bridge (2); Zululand, Malvernia (4); Meinhardskraal Granite, Sandriver Geinss, etcetera (7); Dwyka (8); Transvaal, Rooiberg, Griqualand-West (10); Ecca (12); Adelaide (16); Natal (17); Tugela, Mapumulo (22); Table Mountain (25); and Uitenhage (26) (see Appendix 4av). Nevertheless,

geological features with the greatest influence were: Zululand, Malvernia (4), which had a log response of 3.0 followed by Uitenhage (26) with a log response of 2.8 (see Appendix 4av).

Probability of occurrence map for Miniopterus fraterculus

Areas with a high probability of occurrence for *Miniopterus fraterculus* covered mostly the lowveld region of the Savannah biome of South Africa (see Figure 28). This area extends from Port St John's in KwaZulu-Natal northwards towards the Swaziland border. The northern limit of the area of high probability of occurrence occurred in the interior of Mpumalanga and the eastern parts of the Limpopo Province.

3.1.2.5 A model for One South African Bat Species Limited by Annual Mean Temperature

3.1.2.5.1 *Nycticeinops schlieffeni*

Eight predictor variables and all 26 presence records were considered for modelling the distribution of *Nycticeinops schlieffeni*. The best model was a two-variable model (see Appendices 1u, 2u, 3u) which included the annual mean temperature and geology (see Table 6).

The final two-variable model for Nycticeinops schlieffeni

The MaxEnt response curve exhibited that the log response for *Nycticeinops schlieffeni* reaches 5.5 when the annual mean temperature reaches 24°C (see Appendix 4aw). The value of the log response curve started at zero for the lowest value of the annual mean temperature (17°C); thereafter it increased gradually to 5.5 at 24°C where the curve started to level off. Thus, the limiting value for an annual mean temperature of not less than 17°C restricted the distribution of *Nycticeinops schlieffeni,* which appeared to prefer an annual mean temperature of about 24°C (see Appendix 4aw).

It emerged that six geological features had a positive influence on *Nycticeinops schlieffeni*. These included: Beaufort (1): Barberton, Murchison, Giyani, Beit Bridge (2); Suurberg, Drakensberg, Lebombo (3); Waterberg, Southpansberg, Orange River (5); Meinhardskraal Granite, Sandriver Geinss, etcetera (7); and Ecca(12) (see Appendix 4ax). However, the geological features with the greatest influence were Meinhardskraal Granite, Sandriver Gneiss etcetera (7), which yielded a log response of 1.9. The geological feature that exerted the second greatest influence was Waterberg, Southpansberg, Orange River (5), which had a log response of 1.8 (see Appendix 4ax).

Probability of occurrence map for Nycticeinops schlieffeni

Areas with a high probability of occurrence for *Nycticeinops schlieffeni* covered mostly the Mopane veld region of the Savannah biome in the extreme northeast of South Africa (see Figure 29).

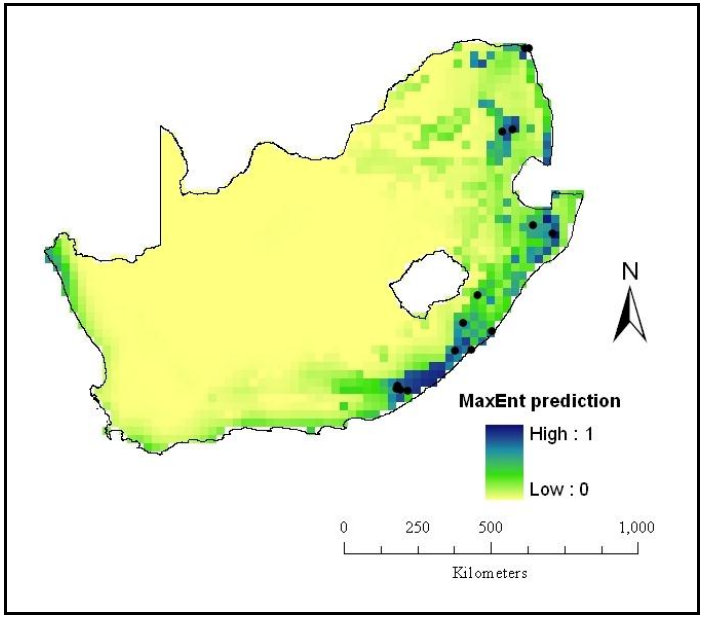

Figure 24. The probability of occurrence for *Rhinolophus swinnyi* in South Africa. The predictions (Low)-(High) depict a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

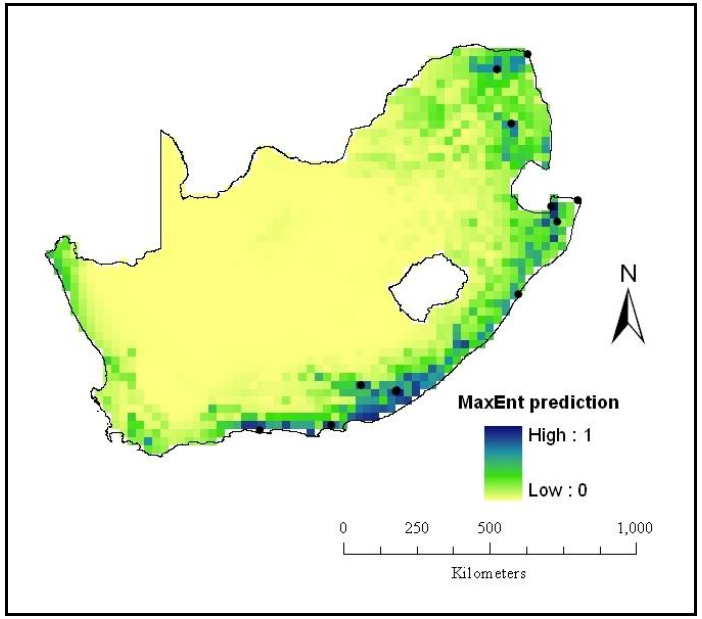

Figure 25. The probability of occurrence for *Kerivoula lanosa* in South Africa. The predictions (Low)-(High) exhibit a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

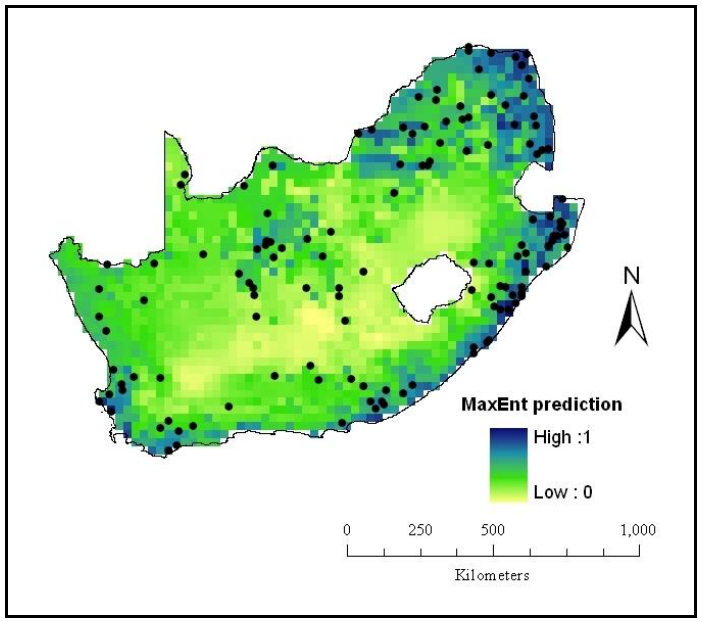

Figure 26. The probability of occurrence for *Nycteris thebaica* in South Africa. The predictions (Low)-(High) indicate a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

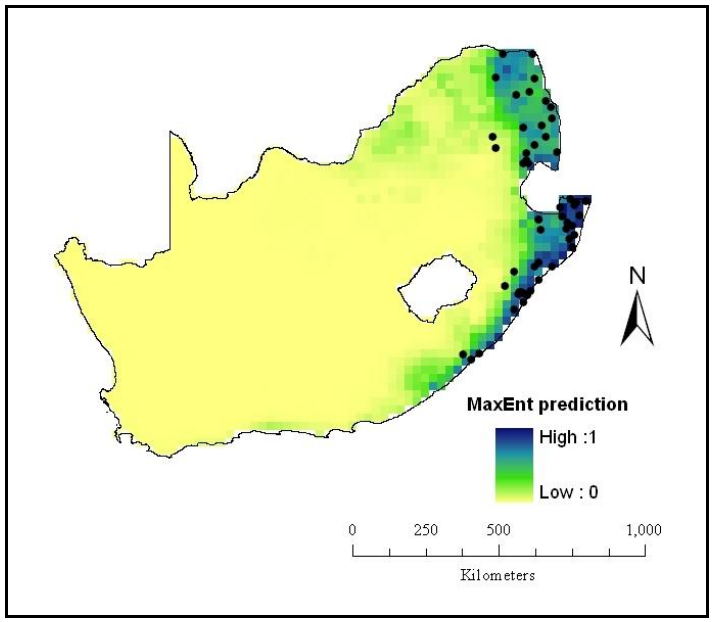

Figure 27. The probability of occurrence for *Neoromicia nana* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

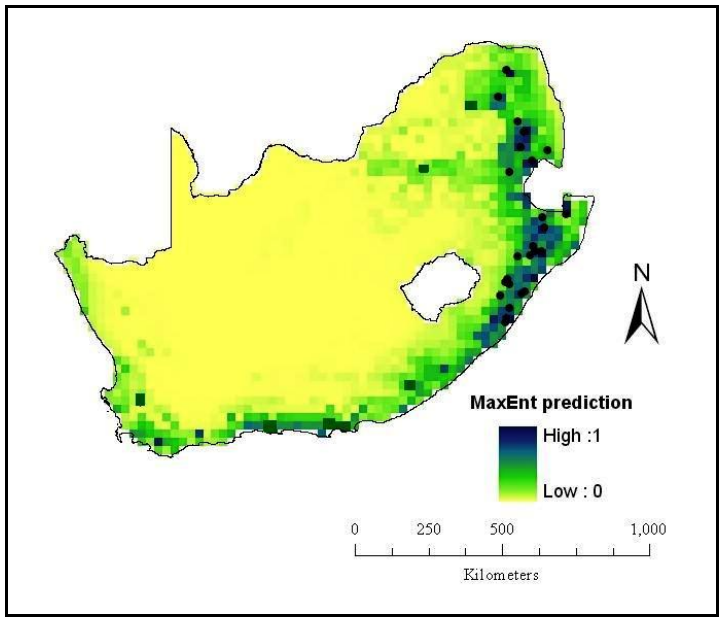

Figure 28. The probability of occurrence for *Miniopterus fraterculus* in South Africa. The predictions (Low)-(High) indicate a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

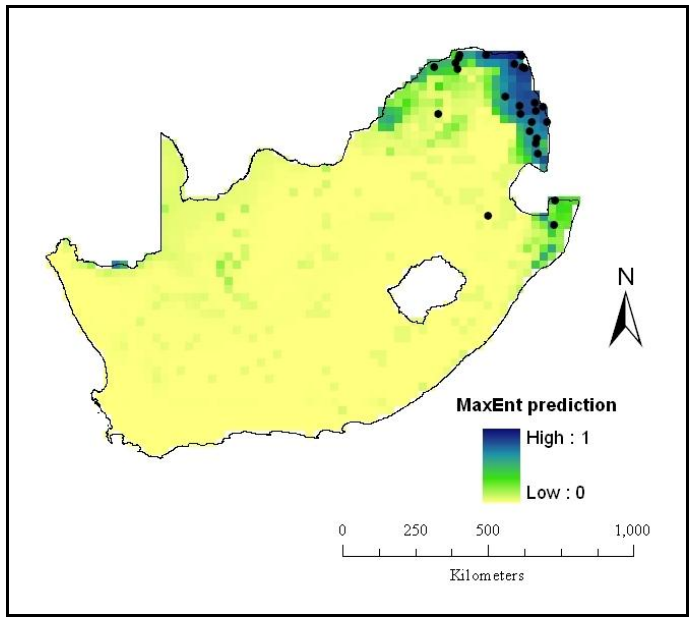

Figure 29. The probability of occurrence for *Nycticeinops schlieffeni* in South Africa. The predictions (Low)-(High) illustrate a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

3.1.3 Models for South African Bats Species Limited by Biophysical Variables

3.1.3.1 Models for the Eight South African Bats Species Limited by Geology

3.1.3.1.1 *Cistugo lesueuri*

Ten predictor variables were evaluated for modelling the distribution of *Cistugo lesueuri* using all 14 presence records for this species. The best model was a three-variable model (see Appendices 1v, 2v, 3v) containing geology, land use/land cover and the mean temperature of the coldest quarter (10.7 %) (see Table 7).

The final three-variable model for Cistugo lesueuri

All 26 geological features had a positive influence on *Cistugo lesueuri* (see Appendix 4ay). However, the geological sub-categories with the greatest influence were: Table Mountain (25) which had a log response of 0.87; followed by Clarens, Elliot, Molteno (18) with a log response of 0.8; and Okiep, Bushmanland, Korannaland, Geelfloer (14) with a log response of 0.76 (see Appendix 4ay).

All 32 land use/land cover types exerted a positive influence on *Cistugo lesueuri*. However, the types with the greatest influence were: cultivated: permanent commercial – irrigated land (3) which had a log response of 0.97; urban/built-up land: residential (13) with a log response of 0.90; and thickets bushland (5) with a log response of 0.67 (see Appendix 4az).

A mean temperature of $\geq 5^{\circ}$C in the coldest quarter limited the distribution of *Cistugo lesueuri*. Additionally, the mean temperature of the coldest three months of the year, that is, about 4°C, appears to be favourable for this species (see Appendix 4ba).

Probability of occurrence map for Cistugo lesueuri

Areas with a high probability of occurrence for *Cistugo lesueuri* covered mostly the mountain

and escarpment grassland and the grassland of the Central Highveld regions of the Savannah biome of South Africa**.** In addition, the Fynbos and Renosterveld region of the Fynbos biome also revealed a moderate probability of occurrence for this species (see Figure 30).

3.1.3.1.2 *Cloeotis percivali*

Ten predictor variables were considered for modelling the distribution of *Cloeotis percivali* based on all 11 presence records for this species. A three-variable model (see Appendices 1w, 2w, 3w) was selected incorporating geology, land use/land cover and isothermality (Table 7).

The final three-variable model for Cloeotis percivali

All of the 26 geological features had a positive influence on *Cloeotis percivali* (see Appendix 4bb). However, the geological features with the greatest positive influence were: Zululand, Malvernia (4), which had a log response of 0.98; followed by Suurberg, Drakensberg, Lebombo with a log response of 0.73; and Transvaal, Rooiberg, Griqualand-West (10) with a log response of 0.6 (see Appendix 4bb).

All land use/land cover types have a positive influence on *Cloeotis percivali* (see Appendix 4bc). However, the three with the greatest influence were: forest and woodland (17), which had a log response of 0.78: urban/built-up land: residential (13) with a log response of 0.74; forest plantations (10) with a log response of 0.73; and cultivated: temporary semi-commercial/subsistence-dryland (27) with a log response of 0.69 (see Appendix 4bc).

The third most restrictive environmental variable for *Cloeotis percivali* after geology and land use/land cover was isothermality (see Appendix 4bd). The MaxEnt response curve illustrated that the log response for *Coleotis percivali* reaches 0.91 when the isothermality reaches 0.66 (see Appendix 4bd). The value of the log response curve started at zero for the lowest value of isothermality 0.44; subsequently, it rose steadily to 0.91 when isothermality was 0.66 where the curve started to level off. Thus, the limiting value of the occurrence of *Cloeotis percivali* was restricted by an isothermality of <0.44 and favoured by an isothermality of approximately 0.66 (see Appendix 4bd).

Probability of occurrence map for Cloeotis percivali

Areas with a high probability of occurrence for *Cloeotis percivali* covered mostly the lowveld and the sweet and mixed bushveld regions of the Savannah biome in the Limpopo, east of Mpumalanga, and north-east of the KwaZulu-Natal Province**.** Additionally, the interior of the KwaZulu-Natal Province also displayed a moderate probability of occurrence for this species despite the absence of locality records for this species from this area (see Figure 31).

3.1.3.1.3 *Eptesicus hottentotus*

Eleven predictor variables were analysed for modelling the distribution of *Eptesicus hottentotus* in South Africa using all 23 presence records for this species. A two-variable model was selected (see Appendices 1x, 2x, 3x) consisting of geology and land use/land cover (see Table 7).

The final two-variable model for Eptesicus hottentotus

The distribution of *Eptesicus hottentotus* was positively influenced by 11 geological features and negatively influenced by 1 one subcategory (see Appendix 4be). However, the three geological sub-categories with the greatest positive influence were: Malmesbury, Kango, Gariep (24), which had a log response of 4.3; followed by Natal (17) with a log response of 2.3; and Table Mountain (25) with a log response of 2.0 (Appendix 4be). Only Barren rock (12) had a negative influence on *Eptesicus hottentotus* (see Appendix 4be).

It was evident that four land use/land cover types had a positive influence while two had a negative influence on the distribution of *Eptesicus hottentotus* (see Appendix 4bf). The four types with a positive influence were: forest and woodland (17), which had a log response of 1.6; cultivated: temporary commercial – irrigated land (1) with a log response of 1.45; forest plantations (10) with a log response of 1.1; and thickets and bushland (5) with a log response of 0.9 (see Appendix 4bf). The two types with a negative influence were: cultivated: temporary commercial dryland (11) which had a log response of -0.9; and unimproved grassland (6) with a log response of -0.1 (see Appendix 4bf).

Probability of occurrence map for Eptesicus hottentotus

Areas with a high probability of occurrence for *Eptesicus hottentotus* are restricted to three distinct parts of South Africa (see Figure 32). The first includes the north-eastern part of South Africa situated in the sweet and mixed bushveld as well as the lowveld regions of the Savannah biome**.** The second part is located in the Kalahari region of the Savannah biome. The third part incorporates the Fynbos and Renosterveld region of the Fynbos biome.

3.1.3.1.4 *Miniopterus natalensis*

Twelve predictor variables were evaluated for modelling the distribution of *Miniopterus natalensis* based on all 133 presence records for this species. A three-variable model (see Appendices 1y, 2y, 3y) was selected containing geology, land use/land cover and precipitation in the coldest quarter (see Table 7).

The final three-variable model for Miniopterus natalensis

It transpired that nine geological features had a positive influence on *Miniopterus natalensis* and nine sub-categories had a negative influence (see Appendix 4bg). However, the geological features with the highest positive influence included: Zululand, Malvernia (4) which had a log response of 1.5; followed by Transvaal, Rooiberg, Griqualand-West (10) with a log response of 1.2; and then Barberton, Murchison, Giyani, Beit Bridge (2); and Natal (17) with a log response of 1.0. Geological features with the most negative influence included: Tarkastad (19) which had a log response of -1.4; followed by Malmesbury, Kango, Gariep (24) with a log response of -0.8; asw well as Clarens, Elliot, Molteno (18) and Bokkeveld (23), each with a log response of -0.6 (see Appendix 4bg).

Futher, it became apparent that 11 land use/land cover types had a positive influence while two had a negative influence on *Miniopterus natalensis* (see Appendix 4bh). The types with the greatest positive influence included: cultivated: permanent commercial dryland (15), which had a log response of 2.3; followed by herbland (14), with a log response of 1.2 as well as waterbodies (8); forest and woodland (17); and degraded: forest and woodland (30); each with a log response of 0.6 (see Appendix 4bh). The two types with a negative influence were shrubland and low

fynbos (2), which had a log response of -1.1; and degraded: thickets and bushland, etcetera (9), with a log response of -0.7 (see Appendix 4bh). Precipitation of the coldest quarter of about 400mm appeared to be preferable for this species (see Appendix 4bi).

Probability of occurrence map for Miniopterus natalensis

Areas with a high probability of occurrence for *Miniopterus natalensis* occurred across most parts of South Africa (see Figure 33). However, the Nama-Karoo biome of South Africa indicated a low probability of occurrence for this species. In addition, the grassland of the Central Highveld of the Grassland biome of South Africa also demonstrated a moderate to low probability of occurrence for this species.

3.1.3.1.5 *Myotis tricolor*

Eleven predictor variables were assessed for the distribution of *Myotis tricolor* by allocating all 42 presence records for this species to the MaxEnt model. A three-variable model (see Appendices 1z, 2z, 3z) was selected comprising geology, the maximum temperature in the warmest month, and land use/land cover (see Table 7).

The final three-variable model for Myotis tricolor

It was evident that 11 geological features exerted a positive influence on *Myotis tricolor* while only 1 subcategory had a negative influence (see Appendix 4bj). However, the geological features with the greatest positive influence included: Tugela, Mapumulo (22), which had a log response of 2.5; followed by Bokkeveld (23), with a log response of 1.9; and Table Mountain (25), with a log response of 1.8. The only geological subcategory with a negative influence was Suurberg, Drakensberg, and Lebombo (3), which had a log response of -0.1 (see Appendix 4bj).

A maximum temperature of <22°C in the warmest month of the year limited the occurrence of *Myotis tricolor,* while it appeared to prefer a maximum temperature of between 27°C and 32°C in the warmest month (see Appendix 4bk).

It transpired that seven land use/land cover types exerted a positive influence, while two had a negative influence on *Myotis tricolor* (see Appendix 4bl). The types with the greatest positive

influence included: urban/built-up land: residential land (13), which revealed a log response of 1.7; followed by forest and woodland (17), with a log response of 1.2; and forest (26), with a log response of 1.0 (see Appendix 4bl). The two negative influence land use/land cover types were: shrubland and low fynbos (2) which had a log response of -1.3; and cultivated: temporary commercial dryland (11), with a log response of -0.6 (see Appendix 4bl).

Probability of occurrence map of Myotis tricolor

Areas with a high probability of occurrence for *Myotis tricolor* were situated in the convergence of the lowveld and the mountain and escarpment grassland regions of the Savannah biome in the northeastern parts of South Africa (see Figure 34). These areas included KwaZulu-Natal, Mpumalanga and the southern parts of the Limpopo Province. A high probability of occurrence for this species is also evident in the convergence junction between the sweet and mixed bushveld as well as the grassland of the Central Highveld regions of the Savannah biome. These areas are located in the eastern parts of the North West Province, and the northern parts of the Gauteng Province. Further, the Fynbos and Renosterveld region of the Fynbos biome also confirmed a high probability of occurrence for this species.

3.1.3.1.6 *Rhinolophus darlingi*

Nine predictor variables were evaluated for the distribution of *Rhinolophus darlingi* by assigning all 53 presence records for this species to the MaxEnt model. The best model was a two-variable model (see Appendices 1aa, 2aa, 3aa) consisting of geology and land use/land cover (see Table 7).

The final two-variable model for Rhinolophus darlingi

It became evident that 12 geological features had a positive influence on *Rhinolophus darlingi* (see Appendix 4bm). However, the geological features with the highest positive influence included: Nama, Vanrhynsdorp (15), which had a log response of 2.8; followed by Barberton, Murchison, Giyani, Beit Bridge (2), with a log response of 2.0; and Transvaal, Rooiberg, Griqualand-West (10), with a log response of 1.9 (see Appendix 4bm).

It further transpired that eight land use/land cover types had a positive influence while three had a negative influence on the distribution of *Rhinolophus darlingi* (see Appendix 4bn). The types with the highest positive influence included: cultivated: permanent commercial – irrigated land (3), which had a log response of 2.0; followed by forest and woodland (17), with a log response of 1.25, as well as forest plantations (10), and cultivated: permanent commercial – sugarcane land (32) each with a log response of 1.2 (see Appendix 4bn). The types with a negative response included: unimproved grassland (6), which had a log response of -1.3; shrubland and low fynbos (2), with a log response of -0.6; and cultivated: temporary commercial dryland (11), with a log response of -0.4 (see Appendix 4bn).

Probability of occurrence map for Rhinolophus darlingi

Areas with a high probability of occurrence for this species were the junction between the lowveld, Mopane veld, sweet and mixed bushveld, as well as the mountain or sour bushveld regions of the Savannah biome of South Africa (see Figure 35). These areas included: KwaZulu-Natal, Mpumalanga and the Limpopo Province. In addition, high probabilities of occurrence for this species were also recorded in the Kalahari region of the Savannah biome of South Africa.

3.1.3.1.7 *Sauromys petrophilus*

Ten predictor variables were assessed for modelling the distribution of *Sauromys petrophilus* using all 30 presence records for this species. A two-variable model (see Appendices 1ab, 2ab, 3ab) was selected comprising geology and land use/land cover (see Table 7).

The final two-variable model for Sauromys petrophilus

It was evident that 11 geological features had a positive influence on *Sauromys petrophilus* (see Appendix 4bo). However, Rustennburg, Lebowa, Rashoop (9) had the greatest influence of the geological features with a log response of 2.8. This was followed by Okiep, Bushmanland, Korannaland, Geelfloer (14), which revealed a log response of 2.2 log; followed by Barberton, Murchison, Giyani, Beit Bridge (2), as well as Nama, Vanrhynsdorp (15), which each had a log response of 2.0 (see Appendix 4bo). Only Ecca (12), which had a log response of -0.2, had a negative influence on the distribution of *Sauromys petrophilus* (see Appendix 4bo).

It also transpired that five land use/land cover types had a positive influence while only one had a negative influence on *Sauromys petrophilus* (see Appendix 4bp). The types with the greatest positive influence included: cultivated: permanent commercial – irrigated land (3), which had a log response of 2.8; followed by herbland (14), with a log response of 2.7; and subsequently, forest and woodland (17), with a log response of 1.0. Unimproved grassland (6), which had a log response of -0.8, was the only type to exert a negative influence (see Appendix 4bp).

Probability of occurrence map for Sauromys petrophilus

An area of high probability of occurrence for this species was the sweet and mixed bushveld region of the Savannah biome in the Limpopo Province of South Africa (see Figure 36). In addition, the Nama-Karoo biome around the Augrabies National park also indicated a high probability of occurrence for this species.

3.1.3.1.8 *Rousettus aegyptiacus*

Ten predictor variables were evaluated for modelling the distribution of *Rousettus aegyptiacus* using all 30 presence records for this species. The best model was a four-variable model (see Appendicees 1ac, 2ac, 3ac) containing geology, annual precipitation, biome, and land use/land cover (Table 7).

The final four-variable model for Rousettus aegyptiacus

It transpired that 12 geology sub-categories had a positive influence on *Rousettus aegyptiacus* (see Appendix 4bq). However, the greatest positive influence was exerted by Uitenhage (26), which had a log response of 3.5; followed by Witwatersrand, Dominion, Pongola (13), with a log response of 3.0; and then Meinhardskraal Granite, Sandriver Gneiss, etcetera (7), with a log response of 1.6 (see Appendix 4bq). An annual precipitation of <50 mm limited the occurrence of *Rousettus aegyptiacus*. Furthermore, an annual precipitation of approximately 1,250 mm would be vital for this species (see Appendix 4br).

It further transpired that three biome types had a positive influence while two had a negative

influence on *Rousettus aegyptiacus* (see Appendix 4bs). Types with a positive influence included: Albany thicket (5) which had a log response of 1.4; followed by Succulent Karoo (0) with a log response of 1.1; and, then Fynbos (1) with a log response of 0.5 (see Appendix 4bs). The two types with a negative influence were Grassland (4), which had a log response of -02.6; followed by Savannah (3) which had a log response of -0.8 (see Appendix 4bs).

It became apparent that 10 land use/land cover types had a positive influence on *Rousettus aegyptiacus* (see Appendix 4bt). The type with the greatest positive influence included: cultivated: permanent commercial dryland (15), which had a log response of 2.5; followed by forest (26), with a log response of 2.0 log; and then degraded: forest and woodland (30); as well as forest plantations (10), which each had a log response of 1.4 (see Appendix 4bt).

Probability of occurrence map for Rousettus aegyptiacus

Areas with a high probability of occurrence for *Rousettus aegyptiacus* were in two distinct parts of South Africa (see Figure 37). The first area was located in the lowveld region of the Savannah biome in the Limpopo Province in northeastern South Africa extending southwards towards the Swaziland border. The southern fringes of this area including the KwaZulu Natal Province confirmed a moderate probability of occurrence for this species. The second part of the high probability of occurrence for this species was located in the Fynbos and Renosterveld region of the Fynbos biome.

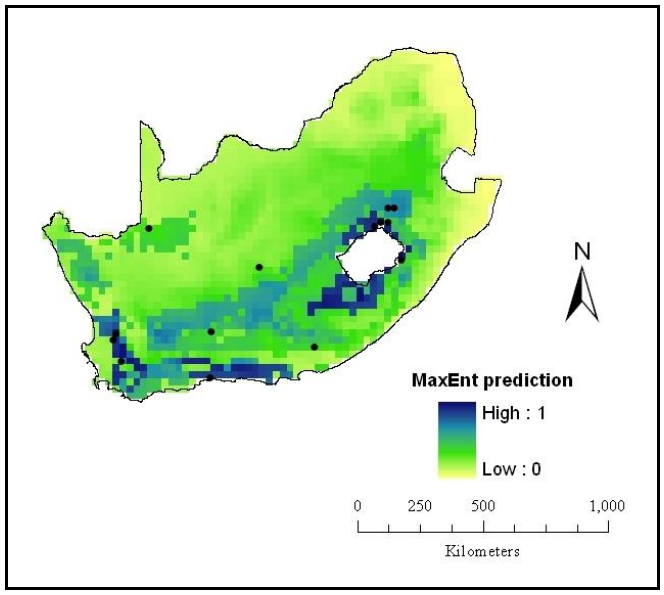

Figure 30. The probability of occurrence for *Cistugo lesueuri* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

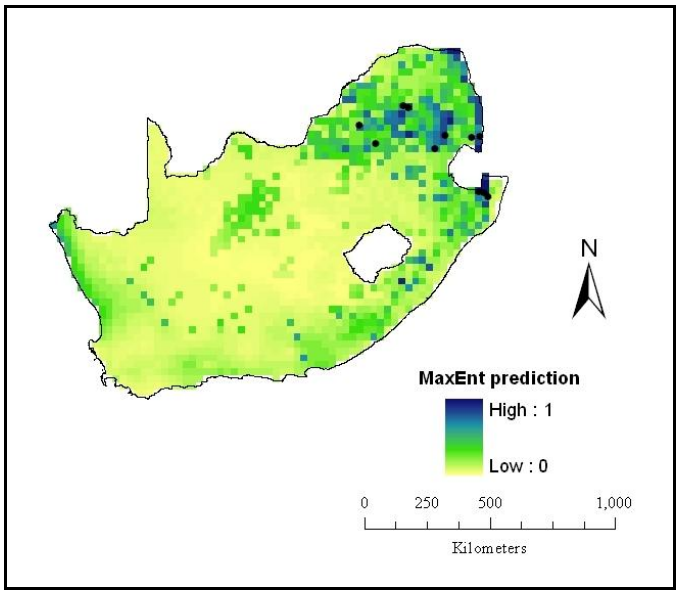

Figure 31. The probability of occurrence for *Cloeotis percivali* in South Africa. The predictions (Low)-(High) indicate a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

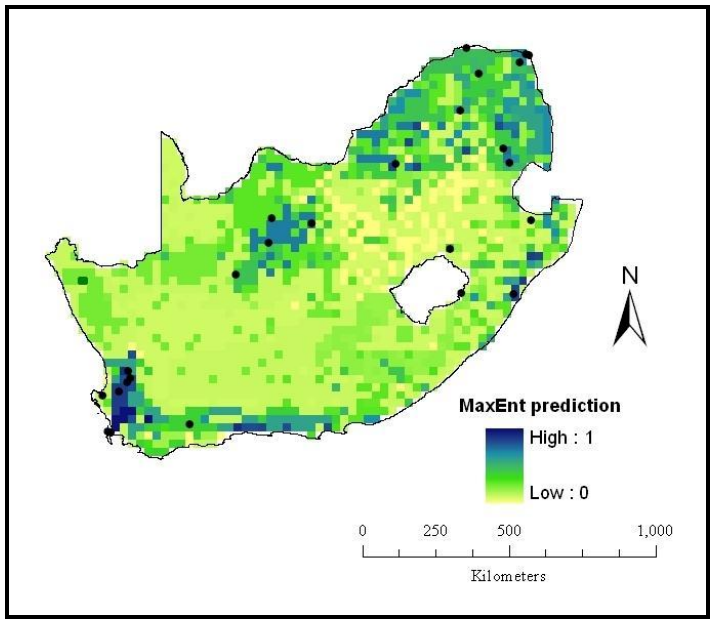

Figure 32. The probability of occurrence for *Eptesicus hottentotus* in South Africa. The predictions (Low)-(High) indicate a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

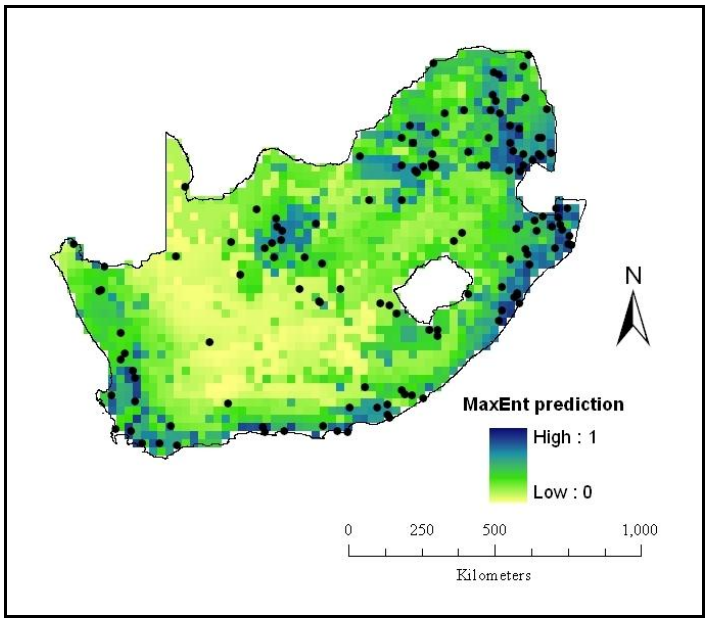

Figure 33. The probability of occurrence for *Miniopterus natalensis* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

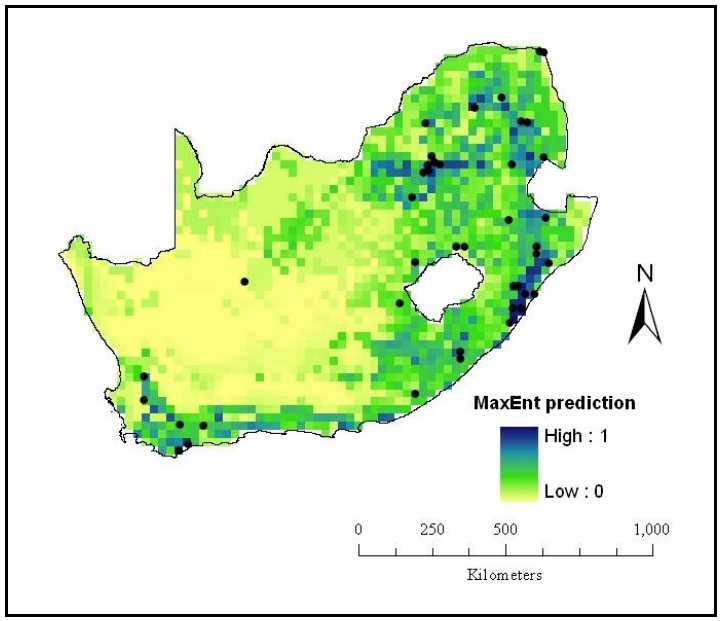

Figure 34. The probability of occurrence for *Myotis tricolor* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

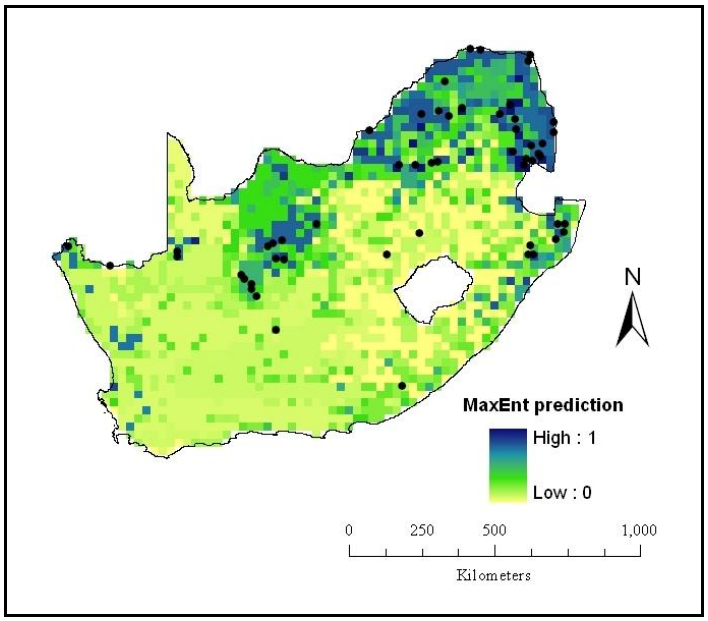

Figure 35. The probability of occurrence for *Rhinolophus darlingi* in South Africa. The predictions (Low)-(High) exhibit a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

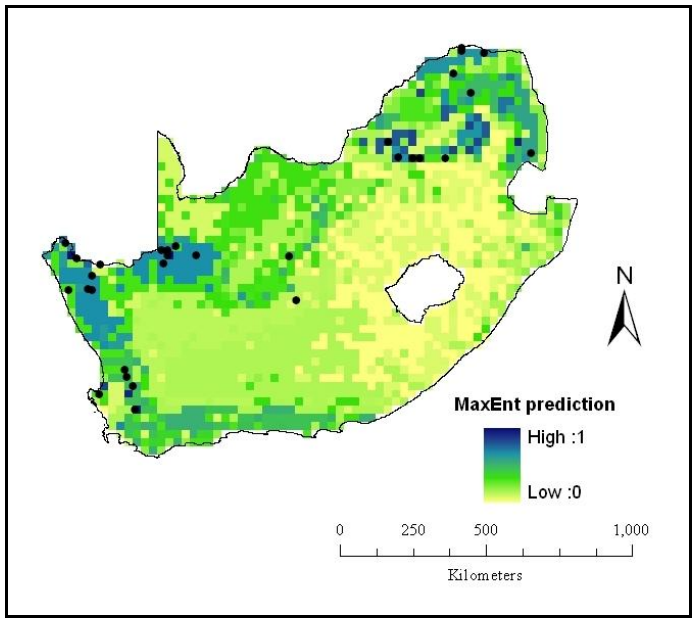

Figure 36. The probability of occurrence for *Sauromys petrophilus* in South Africa. The predictions (Low)-(High) depict a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor), precipitation of the warmest quarter and geology.

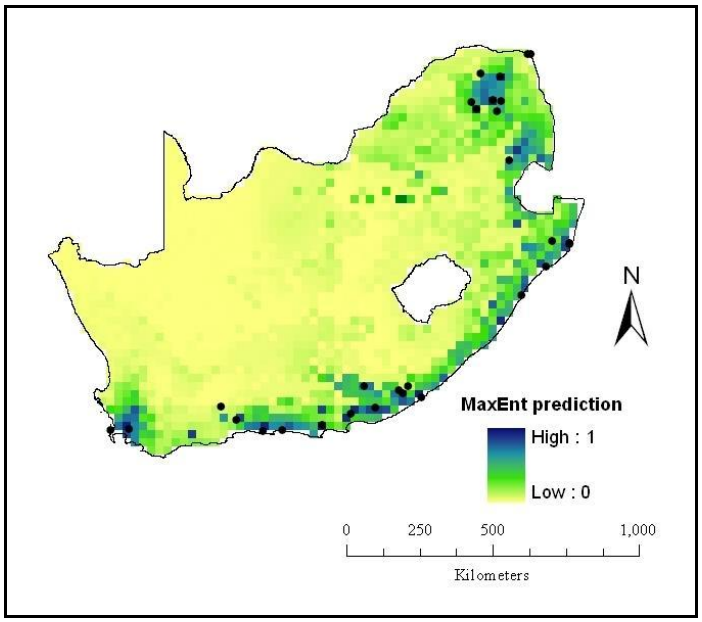

Figure 37. The probability of occurrence for *Rousettus aegyptiacus* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include the mean temperature of the coldest quarter (the strongest predictor) and land use/land cover.

3.1.3.2 Models for the Six South African Bats Species Limited by Land Use/Land Cover

3.1.3.2.1 *Neoromicia capensis*

Ten predictor variables were assessed for the distribution of *Neoromicia capensis* using all 311 presence records for this species. A two-variable model (see Appendices 1ad, 2ad, 3ad) was selected incorporating land use/land cover and geology (see Table 7).

The final two-variable model for Neoromicia capensis

It became evident that 11 land use/land cover types had a positive influence while 3 had a negative influence on *Neoromicia capensis* (see Appendix 4bu). The types with the highest positive influence included: urban/built-up land: commercial (25), which had a log response of 1.4; followed by Waterbodies (8); and Forest (26), which each had a log response of 0.8; and then cultivated: temporary commercial – irrigated land (1), with a log response of 0.6 (see Appendix 4bu). Types with a negative influence included shrubland and low fynbos (2), which had a log response of -0.8; followed by degraded: thickets and bushland, etcstera (9), with a log response of -0.3; and degraded: unimproved grassland (16), with a log response of -0.15 (see Appendix 4bu).

It further emerged that 10 geological features had a positive influence and 12 had a negative influence on *Neoromicia capensis* (see Appendix 4bv). However, the types with the highest positive influence included: Cape Granite (21), which had a log response of 1.4; followed by Natal (17), with a log response of 0.7; and then Clarens, Elliot, Molteno (18); as well as Witwatersrand, Dominion, Pongola (13), each with a log response of 0.5. Types with a negative influence included: Rusternburg, Lebowa, Rashoop (9), which had a log response of -1.4; followed by Tugela, Mapumulo (22), with a log response of -0.6; and then Malmesbury, Kango, Gariep (24), with a log response of -0.4 (see Appendix 4bv).

Probability of occurrence map for Neoromicia capensis

Areas with a high probability of occurrence for this species extend almost all over South Africa (see Figure 38). However, the Nama-Karoo biome exhibits a moderate probability of occurrence despite the fact that there are considerable presence records for this species from this area. In addition, the northern parts of Mpumalanga and Gauteng Provinces also show a low probability of occurrence for this species.

3.1.3.2.2 *Neoromicia zuluensis*

Eleven predictor variables were assessed for the distribution of *Neoromicia zuluensis* using all 20 presence records for this species. A two-variable model (see Appendices 1ae, 2ae, 3ae) was selected consisting of land use/land cover and the mean temperature of the coldest quarter (see Table 7).

The final two-variable model for Neoromicia zuluensis

The land use/land cover types with the highest positive influence included: forest and woodland (17), which had a log response of 3.5; followed by degraded: forest and woodland (30), with a log response of 2.7; degraded: thickets and bushland, etcetera (9), with a log response of 2.5; and then thickets bushland (5), with a log response of 2.1 (see Appendix 4bw). A mean temperature of <5°C in the coldest quarter limited the distribution of *Neoromicia zuluensis* whereas a mean temperature in the coldest quarter of about 19°C appeared to be preferable for this species (see Appendix 4bw).

Probability of occurrence map of Neoromicia zuluensis

Areas with a high probability of occurrence for this species were situated in the Mopane veld and the sweet and mixed bushveld of the Savannah biome of South Africa (see Figure 39). This area includes the Limpopo and eastern parts of the Mpumalanga Province. In addition, the lowveld region of the Savannah biome in northeastern KwaZulu-Natal also had a moderate to high probability of occurrence for this species.

3.1.3.2.3 *Rhinolophus denti*

Eight predictor variables were examined for modelling the distribution of *Rhinolophus denti* using all 12 presence records for this species. A two-variable model (see Appendices 1af, 2af, 3af) was selected comprising land use/land cover and geology (see Table 7).

The final two-variable model for Rhinolophus denti

The land use/land cover types with the highest positive influence included: cultivated: temporary commercial – irrigated land (1), which had a log response of 2.9; followed by thickets bushland (5), which had a log response of 2.7 (see Appendix 4by). It transpired that three geological features had a positive influence on *Rhinolophus denti* (see Appendix 4bz). However, the geological sub-categories with the greatest positive influence included: Ventersdorp (11), which had a log response of 2.1; followed by Transvaal, Rooiberg, Griqualand-West (10), with a log response of 1.3; and then Kalahari (6), with a log response of 0.3 (see Appendix 4bz).

Probability of occurrence map for Rhinolophus denti

Areas with a high probability of occurrence for this species included the Kalahari region of the Savannah biome of South Africa (see Figure 40). In addition, the sweet and mixed bushveld region of the Savannah biome in the Limpopo Province also had some areas with a high probability of occurrence despite the fact that there were no locality records for this species from this area.

3.1.3.2.4 *Tadarida aegyptiaca*

Twelve predictor variables were tested for modelling the distribution of *Tadarida aegyptiaca* using all 140 presence records for this species. A two-variable model (see Appendices 1ag, 2ag, 3ag) was selected comprising land use/land cover and precipitation in the driest quarter (see Table 7).

The final two-variable model for Tadarida aegyptiaca

It emerged that 12 land use/land cover types had a positive influence while 4 had a negative influence on *Tadarida aegyptiaca* (see Appendix 4ca). The types with the highest positive influence included: urban/built-up land: residential (small holding: grassland) (28), which had a

log response of 1.55; followed by Wetlands (4), with a log response of 1.1; and Herbland (14), with a log response of 0.8 (see Appendix 4ca). Types with a negative influence included: cultivated: temporary semi-commercial/subsistence-dryland (27), which had a log response of -0.8; followed by degraded: thickets and bushland (9), with a log response of -0.75; and then shrubland and low fynbos (2), with a log response of -0.4; as well as forest and woodland (17), with a log response of -0.8 (see Appendix 4ca).

Hence, the limiting value for precipitation of < 120mm in the driest quarter restricted the occurrence of this species. On the other hand, a precipitation of 200mm in the quarter of the year appeared to favour *Tadarida aegyptiaca* (see Appendix 4cb).

Probability of occurrence map for Tadarida aegyptiaca

The probability of occurrence for *Tadarida aegyptiaca* is moderate to low all over South Africa (see Figure 41). However, the probability of occurrence for this species is very low in the Nama-Karoo biome of South Africa despite the fact that there are locality records for this species within this biome.

3.1.3.2.5 *Taphozous mauritianus*

Eight predictor variables were considered for modelling the distribution of *Taphozous mauritianus* using all 12 presence records for this species. He selected a three-variable model (see Appendices1ah, 2ah, 3ah) consisting of land use/land cover, annual temperature range and geology (see Table 7).

The final three-variable model for Taphozous mauritianus

The research illustrated that six land use/land cover types had a positive influence while only one had a negative influence on *Taphozous mauritianus* (see Appendix 4cc). The types with the highest positive influence included: urban/built-up land: residential (13), which had a log response of 1.9; followed by forest and woodland (17), with a log response of 1.25; and thickets bushland (5), with a log response of 1.1 (Appendix 4cc). The only type with a negative influence was shrubland and low fynbos (2) which had a log response of -1.25 (see Appendix 4cc).

The second most limiting environmental variable for *Taphozous mauritianus* after land use/land cover was the annual temperature range (see Appendix 4cd). The MaxEnt response curve demonstrated that the log response for *Taphozous mauritianus* reaches 1.8 when the annual temperature range reaches 23°C (see Appendix 4cd). The value of the log response curve started at zero for the lowest value of annual temperature range (14°C). Subsequently, it increased to 1.8 at 23°C where the log response curve descended suddenly; and reached below zero at 31°C. The distribution of *Taphozous mauritianus* appeared to be limited by an annual temperature range of <14°C and favoured by an annual temperature range of between 23°C and 31°C (see Appendix 4cd).

It transpired that 12 geological features had a positive influence on *Taphozous mauritianus* (see Appendix 4ce). However, the geological sub-categories with the greatest positive influence included: Uitenhage (26), which had a log response of 2.8; followed by Natal (17), with a log response of 2.0; and then Waterberg, Southpansberg, Orange River (5), with a log response of 1.7 (see Appendix 4ce).

Probability of occurrence map for Taphozous mauritianus

A high probability of occurrence for this species occurred in the Savannah biome in the northeastern part of South Africa including the Limpopo and Mpumalanga Provinces (see Figure 42). In addition, the KwaZulu-Natal Province also had a moderate to high probability of occurrence for this species even though there were only a few locality records within this area.

3.1.3.2.6 *Myotis welwitschii*

Nine predictor variables were assessed for modelling the distribution of *Myotis welwitschii* in South Africa using all 13 presence records for this. The best model had two variables (see Appendices 1ai, 2ai, 3ai) viz. land use/land cover and precipitation of the warmest quarter (see Table 7).

The final two-variable model for Myotis welwitschii

It became evident that four land use/land cover types had a positive influence on *Myotis welwitschii* (see Appendix 4cf). These included: cultivated: permanent commercial – irrigated land (3); thickets bushland (5); cultivated: temporary commercial dryland (11); and forest and woodland (17) (see Appendix 4cf). However, the type with the greatest influence was cultivated: permanent commercial – irrigated land (3), which had a log response of 3.7; while forest and woodland (17), with a log response of 2.2, had the second greatest influence (see Appendix 4cf).

The second most limiting environmental variable for *Myotis welwitschii* after land use/land cover was precipitation of the warmest quarter (see Appendix 4cg). The MaxEnt response curve confirmed that the log response for *Myotis welwitschii* reached 5.0 when precipitation of the warmest quarter was 600 mm (see Appendix 4cg). The value of the log response curve started at zero for the lowest value of the precipitation of the warmest quarter (10 mm). Thereafter, it increased gradually to 5.0 as precipitation of the warmest quarter reached 600 mm; where the curve leveled off. The distribution of *Myotis welwitschii* was limited by a precipitation of <10 mm and favoured a precipitation of 600 mm in the warmest quarter of the year (see Appendix 4cg).

Probability of occurrence map of Myotis welwitschii

A high probability of occurrence for *Myotis welwitschii* is indicated in the Savannah biome of South Africa (see Figure 43). Specific areas with a high probability of occurrence included the lowveld as well as the sweet and mixed bushveld regions of the Savannah biome in the Mpumalanga and Limpopo Provinces of South Africa, respectively.

3.1.3.3 A model for One South African Bat Species Limited by Biome

3.1.3.3.1 *Rhinolophus capensis*

Eleven predictor variables were evaluated for modelling the distribution of *Rhinolophus capensis* based on all 36 presence records for this species. A three-variable model (see Appendices 1aj,

2aj, 3aj) was selected containing biome, precipitation in the coldest quarter and geology (see Table 7).

The final three-variable model for Rhinolophus capensis

It emerged that four biome types had a positive influence on *Rhinolophus capensis* (see Appendix 4ch). These included: desert (7), which had a log response of 5.6; Albany thicket (5), with a log response of 2.1; Fynbos (1), with a log response of 1.0; and Grassland (4), with a log response of 0.5 (see Appendix 4ch).

The second most restrictive environmental variable for *Rhinolophus capensis* after biome was precipitation of the coldest quarter (see Appendix 4ci). The MaxEnt response curve indicated that the log response for *Rhinolophus capensis* reached 6.2 when precipitation of the warmest quarter reached 450 mm (see Appendix 4ci). The log response curve started at zero for the lowest value of precipitation of the warmest quarter (0 mm), thereafter, it increased sharply to 7.0 at 200 mm where the curve levelled off briefly; again, the log response decended gently to 6.2 at 450 mm where the curve smoothed out. As a consequence, the limiting value of precipitation of <200 mm in the coldest quarter restricted the distribution of *Rhinolophus capensis*. In fact, it appeared that precipitation of between 200 mm and 450 mm in the coldest quarter of the year was vital to this species (see Appendix 4ci).

The third most limiting environmental variable for *Rhinolophus capensis* after biome and precipitation of the coldest quarter was geology (see Appendix 4cj). The response curve indicated that nine geological features had a positive influence on *Rhinolophus capensis*, while only one had a negative influence (see Appendix 4cj). Geological sub-categories with the highest positive influence included: Clarens, Elliot, Molteno (18), which had a log response of 1.5; Okiep, Bushmanland, Korannaland, Geelfloer (14), with a log response of 1.45; as well as Nama, Vanrhynsdorp (15) and Uitenhage (26), which each had a log response of 1.2 (see Appendix 4cj). Adelaide (16), which had a log response of - 2.2, was the only geological subcategory with a negative influence (see Appendix 4cj).

Probability of occurrence map of Rhinolophus capensis

Areas with a high probability of occurrence for *Rhinolophus capensis* included the Fynbos, Albany thickets and the Desert biomes of South Africa (see Figure 44). The interior of South Africa had a very low probability of occurrence.

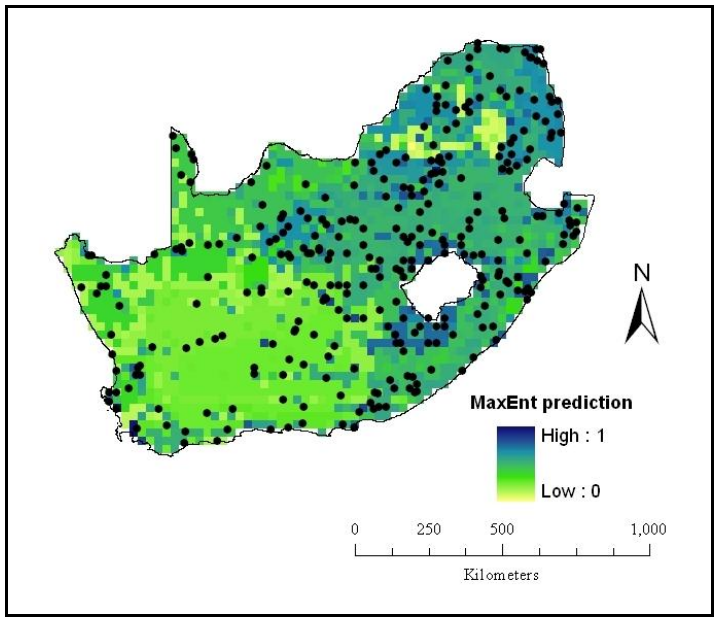

Figure 38. The probability of occurrence for *Neoromicia capensis* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include land use/land cover (the strongest predictor) and geology.

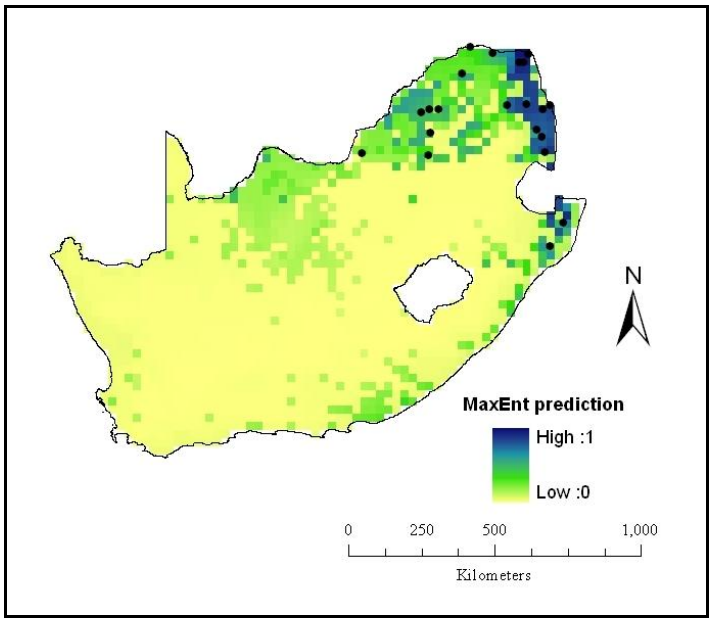

Figure 39. The probability of occurrence for *Neoromicia zuluensis* in South Africa. The predictions (Low)-(High) depict a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include land use/land cover (the strongest predictor) and mean temperature of the coldest quarter.

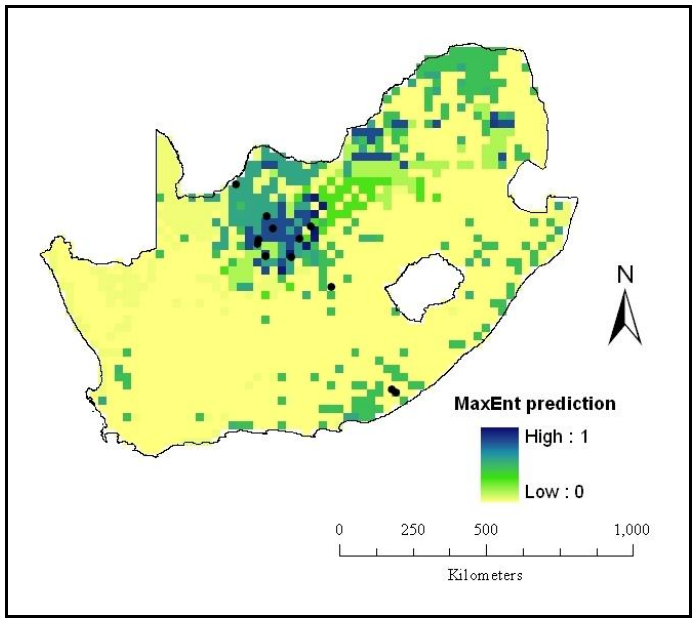

Figure 40. The probability of occurrence for *Rhinolophus denti* in South Africa. The predictions (Low)-(High) depict a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include land use/land cover (the strongest predictor) and geology.

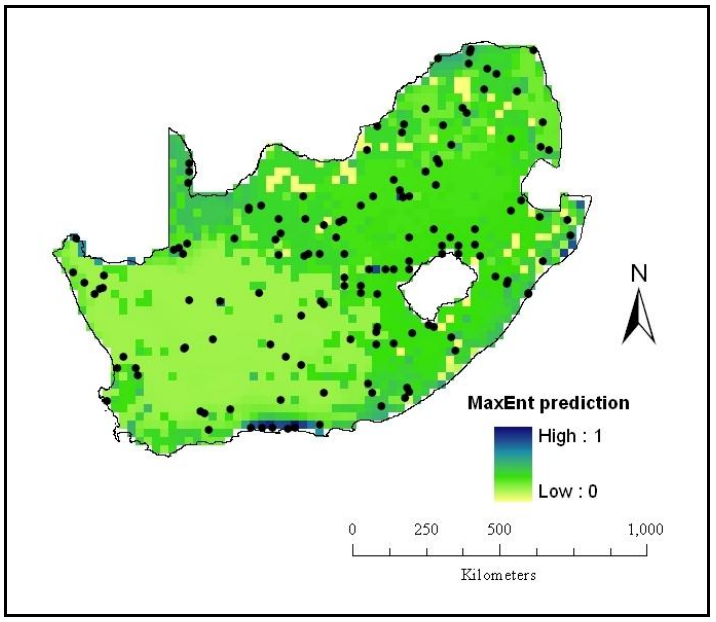

Figure 41. The probability of occurrence for *Tadarida aegyptiaca* in South Africa. The predictions (Low)-(High) indicate a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include land use/land cover (the strongest predictor) and precipitation of the driest quarter.

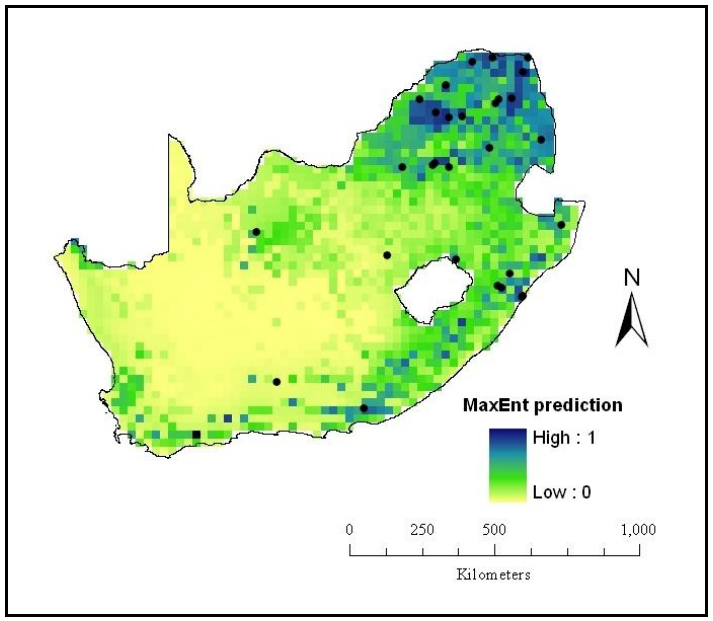

Figure 42. The probability of occurrence for *Taphozous mauritianus* in South Africa. The predictions (Low)-(High) depict a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include land use/land cover (the strongest predictor), temperature annual range and geology.

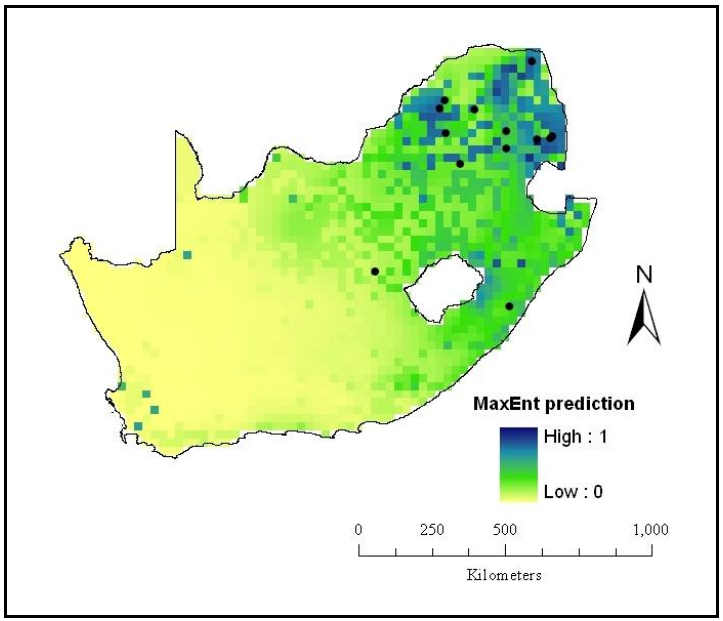

Figure 43. The probability of occurrence for *Myotis welwitschii* in South Africa. The predictions (Low)-(High) indicate a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include land use/land cover (the strongest predictor) and precipitation of the warmest quarter.

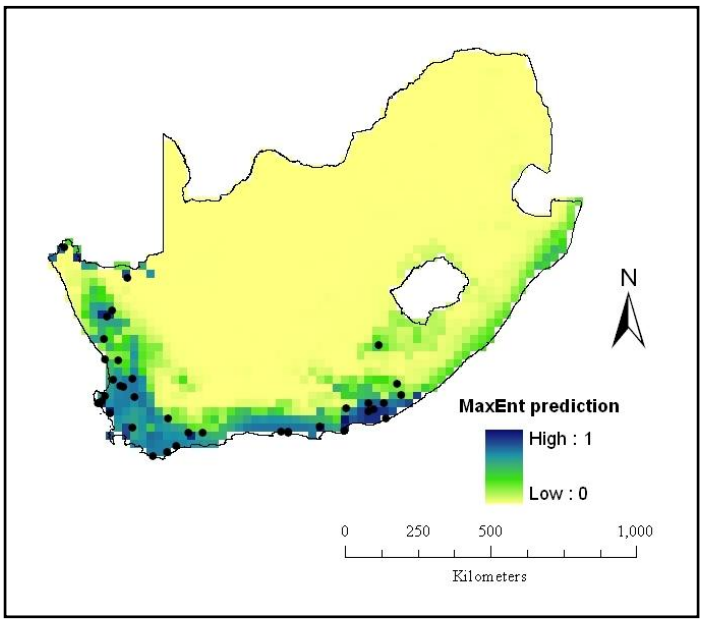

Figure 44. The probability of occurrence for *Rhinolophus capensis* in South Africa. The predictions (Low)-(High) reveal a suitability gradient from 0-1 based on environmental suitability where 0 (low) indicates a zero probability of occurrence and 1 (high) indicates a maximum probability of occurrence. Black dots indicate locality records used for modelling the species. Variables used in the final model include biome (the strongest predictor), precipitation of the coldest quarter and geology.

Chapter 4

DISCUSSION

In accordance with the thesis prediction, taxonomic affiliations appear to have no bearing on which factors influence the geographic distribution of South African bat species. The distributional limits of even congeneric species are influenced by disparate environmental factors. For example, *Rhinolophus clivosus* and *Rhinolophus darlingi* (Genus Rhinolopus) were influenced by annual precipitation and geology respectively. Despite this, some general patterns have emerged. Geology appears to be the important limiting factor for 15 of the 37 species, all of which are known to use roosts associated with geological features (i.e., caves, mines and rock crevices). The next most important limiting factors in order of importance were land use/land cover (six species), mean temperature of the coldest quarter (six species), precipitation seasonality (four species) and annual precipitation (three species). Of less importance were precipitation of the warmest quarter; temperature seasonality; minimum temperature of the coldest month, which influenced the distribution of two bats species each as well as temperature annual range; annual mean temperature; and biome, which influenced the distribution of only one bat species each.

4.1 Geology

As predicted, geology emerged as the most or second most important variable influencing the distribution of crevice-, mine-, or cave-dwelling bat species in South Africa (Tables 5, 6, and 7). Most sub-categories of geology influencing the distribution of bats in South Africa are conducive to the formation of caves or crevices, or accommodate both abandoned and active mines in South Africa. For example, the geological sub-categories of Malmesbury, Kango, and Gariep Groups had the most influence on the distribution of *Eptesicus hottentotus* (i.e., roosts in caves (Skinner and Chimimba 2005)), and rock crevices (Herselman and Norton 1985). The Malmesbury group consists of limestones (cave-forming rocks) and the famous Cango caves, which are situated within this group (du Toit 1954). The Gariep Group contains sedimentary rock from which rugged mountain ranges are formed, and includes limestones besides other rock types (Viljoen and Reimold 1999). Another example is *Rhinolophus*

darlingi whose distribution is influenced mostly by the Nama, Vanrhynsdorp geological sub-categories followed by the Barberton, Murchison, Giyani, Beit Bridge groups (see Appendix 4bn). The Nama, Vanrhynsdorp geological sub-categories consist of sub-horizontal sediments-sandstone, shale and limestones (Norman and Whitfield 2006). The Barberton subcategory is a rugged area in the lowveld region of the Mpumalanga Province and where many gold mines exist (Viljoen and Reimold 1999). The Murchison subcategory is a narrow belt that extends south of Tzaneen to the Kruger National Park. It hosts many small gold deposits and the Beit Bridge complex consists of marble and cal-silicate rock (metamorphosed limestone or dolomite) (Viljoen and Reimold 1999).

The distributions of eight rhinolophids (all cave or crevice-dwellers) were all influenced by geology, as being either the most or second most important variable. Furthermore, all of the seven non-rhinolophid bat species whose distributions were influenced by geology also use caves or rock crevices as roosting sites (see Table 7). For example, *Cistugo lesueuri* (Family Vespertilionidae) uses rock crevices as roosting sites (Lynch 1994; Watson 1998), and *Cloeotis percivali* (Family Hipposideridae) roosts in caves (Monadjem *et al.* 2010) or may roost in narrow rock crevices (Seamark 2005). Furthermore, *Rousettus aegyptiacus*, the only fruit-eating bat whose distribution is strongly influenced by geology, is totally dependent on caves for roosts (Monadjem *et al.* 2010).

Among the four species of bats for which geology was the second most important variable, two species, *Mops midas* and *Nycticeinops schlieffeni* use rock faces and crevices (*Mops midas*; Fenton *et al.* 1994) and crevices (*Nycticeinops schlieffeni*; Rosevear 1965; Verschuren 1957a). However, the remaining two species for which geology was the second most important variable, *Kerivoula lanosa* and *Scotophilus viridis*, do not appear to use geology-related roost types (i.e., caves, mines and rock crevices). This could be due to insufficient information on the range of roosts used by both of theses species in South Africa (Monadjem *et al.* 2010) or perhaps there is something about geology that limits their distribution. *Scotophilus viridis* is a roost generalist and might use roosts associated with geological features, which have not yet been documented. Previous studies have indicated that this species roosts in a variety of shelters during the day, including holes in trees (Monadjem *et al.* 2010) and roofs of houses (Jacobs *et al.* 2007b; Jacobs and Barclay 2009).

Another exception was that of *Rhinolophus capensis*. Despite being a cave rooster like the

other rhinolophids in this study, geology was only the third most important factor limiting the distribution of this species. Instead, biome and winter precipitation appeared to be more important in limiting its distribution (see below).

The results of the current study support previous reports that the distribution of African bat fauna, especially cave- and crevice-dwelling species, are closely linked to particular formations of granites, sandstones and limestones that have crevices and caves worn and weathered into these rock formations (Monadjem *et al.* 2010). In Southern Africa, some confined structures of limestones in ironstones and greenstones have created cave systems that form important bat roosts (Cotterill, unpublished data). In South Africa, caves and sinkholes typify the exterior weathering of the dolomites that are soluble to some degree, and the large cave systems that formed in these rocks are important for cave- and crevice-dwelling bat species (Monadjem *et al.* 2010). For example, caves at the Cradle of Humankind in Gauteng provide vital roosting resources for the breeding and non-breeding colonies of the Natal long-fingered bat, *Miniopterus natalensis* (Monadjem *et al.* 2010).

Elsewhere outside Africa, previous studies report the importance of geology-related roost structures (i.e., caves, crevices and mines) for bat distributions especially in arid regions. In such regions, geology-related roosts may offer ephemeral relief from extreme temperature or low humidity (Kingsley *et al.* 2001). These roosts may also be used as den sites, nest substrates, hunting spots for predators or hiding places in order to escape from predators (Halvorson *et al.* 2010). The deposits of limestone and gypsum in the Chihuahuan Desert of New Mexico, United States of America, harbour many caves that support a considerable bat fauna particularly the Brazilian free-tailed bat *Tadarida brasiliensis* (Strong and Goodbar 2005). It has also been reported that the endangered gray bat *Myotis grisescens* is distributed in a limited geographic range in limestone karst areas of the southeastern United States (Rabinowitz and Tuttle 1980). In addition, the Stoliczka's trident bat *Aselliscus stoliczkanus* has been found only in limestone karst areas of Myanmar in tropical southeast Asia (Struebig *et al.* 2005). Further, *Rhinolophus malayanus* appear to be a common species distributed in the limestone karst areas of eastern and southern Myanmar (Struebig *et al.* 2005).

Underground mines have also been reported as important roosting sites for bats. Such abandoned underground mines are crucial for bats that roost in hollows (Altenbach and

Pierson 1995; Kunz and Lumsden 2003). For example, previous studies found that bats use approximately 70 percent of the underground mines in the northern and eastern United States of America (Tuttle and Taylor 1994). Although there are no detailed studies relating the distribution of mines to bat species distributions in Southern and South Africa, all South African cave-roosting bats also use mines (see Monadjem *et al.* 2010).

In general, apart from a few exceptions, geology appears to be a limiting factor for South African bats that use caves/crevices or other geological features as roosts. It also appears that geology is unimportant to the distributions of bat species that do not use geological features as roosts.

4.2 Land use/land cover

Influences of land use/land cover on South African bats (see Table 7) are of particular interest, as they are an indicator of the human impact on natural fauna and usually necessitate some kind of conservation intervention. Land use/land cover types were the most important factors influencing the distribution of 6 of the 37 species of bats included in this study (see Table 7) and the second most important factor in 10 species (see Tables 5, 6, and 7). As expected, land use/land cover appeared as the most important variable influencing the distribution of South African bats that are known to use human structures or domesticated crops as roosting sites. Hence, the distributions of 16 of the 37 species were influenced by land use/land cover in various ways. For example, *Taphozous mauritianus* which is positively influenced mostly by residential urban/built-up land (Appendix 4cc), roosts in a variety of locations associated with human structures, including the walls of buildings (Monadjem *et al.* 2010). Similarly, *Myotis welwitschii,* which is positively influenced mostly by commercially cultivated and irrigated land (Appendix 4cf), has been collected from furled banana leaves although little is known regarding its roosting habitats (Smithers and Wilson 1979). It appears that *Myotis welwitschii* may well be dependent on banana trees as roosting habitats. A high probability of occurrence for *Myotis welwitschii* is predicted for the Mpumalanga Province (see Figure 43) where large-scale commercial forestry and commercial irrigated agriculture, mainly for tropical and subtropical fruit, including bananas, are common (Woodhouse 1995). This provides further support for the view that roost availability may be the most important

factor limiting the distribution of bat species in South Africa.

There is one exception, however. The distribution of *Rhinolophus denti* appeared to be positively influenced mostly by temporary commercially cultivated and irrigated land, followed by thicket bushland (see Appendix 4by), for which there is no apparent link to the roosting habitats reported for this species. Apart from caves, this species has also been found roosting under the thatched roof of a house and in a road culvert (Shortridge 1934). Unravelling the linkage between the environmental variables that seem to influence the distribution of *Rhinolophus denti* is challenging owing to the fact that the core distribution range of this species covers the western parts of southern Africa and extends only marginally into the arid Northern Cape Province of South Africa (current study; Monadjem *et al.* 2010). Therefore, the use of only a portion of the distribution of this species in the current study could have lead to ambiguous results being reported, which may have been caused by differences in local habitat selection. Local ecological conditions may differ significantly for sub-populations between diverse areas within the distribution range (Stockwell and Peterson 2002; Murphy and Lovett-Doust 2007). A species might experience different habitat requirements in discrete parts of its distribution range (Choler and Michalet 2002). Therefore, *Rhinolophus denti* might have different habitat requirements in South Africa, which is only a part of its southern African distribution.

An alternative explanation for the association of this species with temporary commercially cultivated and irrigated land, followed by thicket bushland (see Appendix 4by) might perhaps suggest that this species has adapted to arid land where there are human-made water sources. The current study shows a high probability of occurrence for this species in the arid Kalahari region of the Savanna biome of South Africa (see Figure 40). In addition, previous studies report that the distribution of *Rhinolophus denti* extends from the Northern Cape northwards into Namibia and Botswana, always associated with arid habitats (Maree and Grant 1997; Monadjem *et al.* 2010). In arid environments, the distribution and abundance of species, especially mammals are influenced by local water availability mostly during dry and hot periods (Krausman *et al.* 2006). Local water availability is crucial in arid environments owing to water shortage and the concentration of vegetation around water sources (Hillel and Tadmor 1962). Vegetation concentration around water bodies positively influences the availability of insect prey and determines the quality of foraging habitats (Biscardi *et al.*

2007; McCain 2007). For example, the majority of bat species found in the arid Central Negev Desert of Israel use human-made water bodies for either drinking or foraging. In fact, the abundance of two bat species *Pipistrellus kuhli* and *Tadarida teniotis* have increased in the Negev Desert in the previous century due to human settlement. In that study *Pipistrellus kuhli* used water bodies for drinking and foraging, while *Tadarida teniotis* used water bodies for drinking only (Razgour *et al.* 2010). It is therefore likely that the current distribution of *Rhinolophus denti* has been influenced by water sources, and the resultant improvement in foraging habitats, which became available as a result of human settlement.

It appears that the influence of land use/land cover as the second most important variable on the distribution of South African bats is related to the functional foraging strategies of those bats (see Schoeman and Jacobs 2011). Among the 10 bat species whose distribution were influenced by land use/land cover as being the second most important variable (see Tables 5, 6, and 7), six species (60%) were clutter-edge foraging strategists that belong to the family Vespertilionidae (4 species) and Miniopteridae (2 species). Of the remaining four species, two species were clutter-foragers, *Cloeotis percivali* (Family Hipposideridae) and *Rhinolophus darlingi* (Family Rhinolophidae); one species was an open-air forager, *Sauromys petrophilus* (Family Molossidae) and one species was a fruit-eating bat, *Epomophorus crypturus* (Family Pteropodidae). Previous reports suggest that most clutter-edge foraging bats bats are associated with particular land use/land cover type. For example, *Pipistrellus rusticus* whose distribution was mostly influenced by barren rock along with thickets and bushland and other land use/land cover types (see Appendix 4j), has been found to be locally common in mopane woodland in the Limpopo valley where rocky habitat (clarens sandstones), and therefore an edge habitat, is also present (Monadjem *et al.* 2010). Similarly, *Eptesicus hottentotus,* whose distribution was influenced positively by forest and woodland as well as other land use/land cover types as being the second most important variable (see Appendix 4bf), has been found to occur in miombo woodlands in gorges and granitic hills in Zimbabwe (Cotterill 1996a), while in South Africa it has usually been captured near rocky outcrops (Monadjem *et al.* 2010).

Of the four species that are non clutter-edge foragers whose distribution was influenced by land use/land cover as the being second most important variable, forest and woodland appeared to be among the top three variables that positively influence the distribution of these

species. For example, forest and woodland was the top variable in the land use/land cover subcategory influencing the distribution of *Cloeotis percivali* (see Appendix 4bc; Monadjem *et al.* 2010). Similarly, forest and woodland was the second most influential variable in the land use/land cover subcategory influencing the distribution of *Rhinolophus darlingi* (see Appendix 4bn); this supports previous studies that report that *Rhinolophus darlingi* is primarily a savannah woodland species (Skinner and Smithers 1990; Monadjem *et al.* 2010).
In general, bat species whose distributions were influenced mainly by land use/land cover appear to rely on human-induced structures for their roosting requirements as well as on human-made sources of water that could indirectly enhance their foraging habitats. Land use/land cover as the second most influential variable in the distribution of South African bats appears to be related to the foraging strategies of those bats. However, the results of this study must be interpreted with caution. Thorough knowledge of the life history and ecology of these bat species is needed before correct interpretation of the results of the current study can be undertaken.

4.3 Biome

The current study found no support for the hypothesis that biomes containing vertically structured habitats limit the distribution of more species than the less vertically structured habitats. This could be due to the manner in which biomes are characterised in this study. For example, forests and woodlands are found in more than one biome, subsuming their importance in the analysis, which could result in a situation where biomes containing forests and woodlands did not appear as being important limiting factors. However, the analyses on land use/land cover in the current study confirm that for several species forests and woodlands were important. It seems that land use/land cover analyses are more advantageous than biomes in supporting the hypothesis that vertically structured habitats limit the distribution of more species than the less vertically structured habitats. This could be due to the relatively small-scale characterisation of the land use/land cover compared to biome types in South Africa.

The distribution of only one South African bat species, the endemic *Rhinolophus capensis* (see Table 7), was found to be associated with biome as being the most important predictor

variable. None of the South African bat species distributions were influenced by biome as a second most important variable. The Desert, Albany thicket, and Fynbos biomes were the most influential variables positively influencing the distribution of *Rhinolophus capensis* (see Appendix 4ch). All these biomes are located within the winter rainfall region of South Africa and it could be precipitation in winter, rather than biome per se, that may be limiting the distribution of *Rhinolophus capensis*. In fact, precipitation in the coldest quarter of the year was the second most important variable influencing the distribution of this species (see Appendix 4ci). Precipitation of < 200 mm in the coldest quarter limited the distribution of *Rhinolophus capensis*, and precipitation in the coldest quarter of ≥ 450 mm seemed to positively influence the distribution of this species (see Appendix 4ci). This supports previous studies that reported that annual precipitation in the Cape Province (where the core distribution of this species is predicted) varies from approximately 200 mm in the arid borders and coastal forelands to ≥ 3,000mm in the high mountain plateaus (Miller *et al.* 1983). It has been noted that *Rhinolophus capensis* occurs along the coastal areas of the Northern Cape, Western Cape and Eastern Cape Provinces of South Africa where caves are available for roosting (Skinner and Smithers 1990). Without more knowledge on the biology of these species it is difficult to offer valid explanations for the influence of winter precipitation on the distribution of *Rhinolophus capensis*. However, Skinner and Smithers (1990) noted that the distribution of this species is mainly influenced by the availability of caves and food supply rather than any other environmental factors. Although, variation in insect abundance in response to rainfall has not been well documented in the winter rainfall regions of South Africa, rainfall during winter may result in the emergence of some insects thereby increasing the availability of insect prey at the time of year when summer rainfall regions have few insect preys. Previous studies provide some evidence of a correlation between insectivorous bird abundance and winter rainfall in South Africa. In the South African Fynbos Biome (i.e., a winter rainfall region), winter bird community structures remain stable with only slight increases in the numbers of individuals (Winterbottom 1968). In addition, early-nesting birds show a larger clutch size than late-nesting birds in the winter rainfall regions in the Fynbos and Succulent Karoo biomes in the south-west of South Africa (Lepage and Lloyd 2004). There is a large influx of *Rhinolophus capensis* into the De Hoop Guano cave (situated more or less in the centre of the winter rainfall region) during the winter period (McDonald *et al.* 1990a). This could also be related to the reproductive cycle of this species rather than foraging, because males store spermatozoa in the epididymis during winter

(Bernard 1985, 1986).

4.4 Precipitation variables

As predicted, precipitation parameters were the most important factors influencing South African bat species whose distributions are centred towards the wet east of the country. Precipitation variables appeared as the most important factor influencing the distribution of 10 of the 37 species of bats included in this study (see Table 5) and the second most important factor in 11 other species (see Tables 5, 6, and 7). Thus the distributions of 19 of the 37 species were influenced by precipitation in one form or another and 3 of the 19 species were the fruit-eating species, *Eidolon helvum*, *Epomophorus wahlbergi* (see Table 5) and *Rousettus aegyptiacus* (see Table 7). Most bat species for which precipitation was the most important variable influencing their distribution have their distribution ranges centred towards the east or northeast of South Africa (see Figures 8, 9, 10, 12, 13, 14, 15, and 16). The exceptions were *Eidolon helvum* (see Figure 11), which has a high probablitiy of occurrence in the central grassland of South Africa and *Neoromicia melckorum* (see Figure 17), which has a high probablitiy of occurrence in the west and southwestern parts of South Africa.

Bat species, for which precipitation was the second most important variable, have their distribution ranges centred towards the east or northeast of South Africa (see Figures 18, 20, 22, 26, and 37). The exception was *Tadarida aegyptiaca* (see Figure 41) which has a moderate probability of occurrence all over South Africa due to perhaps unlimited roost availability as it uses human structures. Other exceptions were the two species, *Eidolon helvum* and *Neoromicia melckorum* whose distributions were influenced by precipitation variables only as the most and the second most important variables, respectively.

The importance of precipitation is probably linked to its effects on the availability of food in the form of fruit or insects. In Africa, peak flowering commences more or less a month after peak rainfall (Hepburn and Radloff 1995; Cumming and Bernard 1997). Among the fruit bats in Africa, including those in subtropical southern Africa, parturition is positively correlated with peak rainfall (Cumming and Bernard 1997). Lactation in mammals is the most exhausting part of the reproductive cycle in terms of energy use for the mother as it can

increase energy demands on females from 66-133 percent (Millar 1978). Therefore, lactation should correspond with a period of peak food availability (Racey 1982; Speakman and Racey 1987). This is supported by the findings of a study in KwaZulu-Natal, South Africa, where the highest number of lactating *Epomophorus wahlbergi* occurred in December; while rainfall was uniformly high from November to February and peak fruiting occurred in January (Sowler 1983).

The correlation between precipitation and insect abundance is well documented. In continental Africa, including southern Africa, insect abundance was highly correlated with the rainfall in the previous month, followed by rainfall in the same month (Cumming and Bernard 1997). Similar results have been obtained in continental North America where insect abundance was positively correlated with precipitation in a study that covered the period from 1978-1996 (Bradford and Holyoak1998).

African vespertilionids confirmed similar results as pteropodids with respect to their response to precipitation variables. Parturition in insectivorous bats in Africa, including southern Africa, was positively correlated with the amount of rainfall in the previous month (Cumming and Bernard 1997). Findings from elsewhere in the tropics demonstrated similar relationships between the timing of bat reproduction, food resources and amount of rainfall. Reliance on sufficient food supplies during lactation makes rainfall the most significant climatic factor affecting bat reproductive cycles in the tropics, as it influences the phenology of insects and plants (Racey 1982).

Two of the three South African bat species, *Rhinolophus clivosus* and *Pipistrellus hesperidus*, whose distributions were associated most strongly with annual precipitation (see Table 5) are insectivorous and the third, *Epomophorus wahlbergi*, is a frugivore. However, all three exhibit a wide distributional range in South Africa. A decreasing probability of occurrence from east to west for all three species predicted by the current study is analogous to trends in the mean annual precipitation (2000mm) in the wet east to (< 800 mm) in the dry west of South Africa (Wessels *et al.* 2007). Interestingly, the favourable amount of annual precipitation is identical for the three species (i.e.,1250 mm) (see Figure 7a, and Appendices 4a and 4c). The only difference is the limiting amount of annual precipitation which was approximately 50mm or less for both *Rhinolophus clivosus* and *Pipistrellus hesperidus*, and

200 mm or less for *Epomophorus wahlbergi*. This clearly suggests that *Rhinolophus clivosus* and *Pipistrellus hesperidus* can withstand more arid conditions than *Epomophorus wahlbergi*. Fruit availability for *Epomophorus wahlbergi* may be limited to more mesic areas and this could be the factor that limits the distribution of this species in arid regions of South Africa. This is also reflected in the predicted distribution of these three species. The distribution of *Rhinolophus clivosus* (see Figure 9) overlaps with that of *Epomophorus wahlbergi* (see Figure 8) and *Pipistrellus hesperidus* (see Figure 10). However, the range of *Rhinolophus clivosus* extends into the arid interior and west of the country as well as to the southeastern Cape Province (see Figure 9). The spread of *Rhinolophus clivosus* into the drier areas of South Africa, unlike *Pipistrellus hesperidus* which is also insectivorous, could be linked to the influence of the second most important variable on the distribution of these two species, geology and land use/land cover for *Rhinolophus clivosus* and *Pipistrellus hesperidus*, respectively. This could be related to roost availability that appears to be sufficient for *Rhinolophus clivosus* but not for *Pipistrellus hesperidus*. Geology could provide sufficient roost sites for *Rhinolophus clivosus* as it is a roost generalist that could use all geology-related roosts. In contrast, tree roosts are unlikely to be abundant for *Pipistrellus hesperidus* which is often associated with wooded areas that are scarce in the dry west of South Africa.

All four South African bat species whose distributions were influenced by precipitation seasonality as the being most important variable (see Table 5) are distributed within the subtropical biomes (Savannah and Grassland). The distribution of three species (i.e., *Mops midas, Pipistrellus rusticus* and *Rhinolophus hildebrandtii*) were predicted mainly within the Savannah biome in the northeastern parts of South Africa (Figures 12, 13, 14). This region is characterised by high rainfall seasonality (high amounts of rainfall mostly in summer). The distribution of the fourth species, *Eidolon helvum,* was predicted within the Grassland biome of the central plateau region of South Africa. This species is a non-breeding migrant to South Africa; there is a lack of information on its ecology in Southern Africa (Monadjem *et al.* 2010). However, Richter and Cummings (2006, 2008) proposed that seasonal variation in food availability is the main factor influencing the annual migration of this species to Kasanka National Park, Zambia. However, this cannot explain the predicted disribution of this species in South Africa within the grasslands of the Free State Province since this area is not known to have fruits. Therefore, the results for this species should be interpreted with caution as this is a non-breeding species in South Africa and its ecology and life history is

less known in this region.

The distribution of *Pipistrellus rusticus* and *Rhinolophus hildebrandtii* overlapped (see Figures 13, 14). Moreover, these two species were identically influenced by precipitation seasonality of 10 percent as a limiting variable, and favoured by a precipitation seasonality of 90 to 100 percent (see Appendices 4i, 4l). However, the foraging ecologies of these two species are different; *Pipistrellus rusticus* is a clutter-edge forager and *Rhinolophus hilderbrandtii* uses a clutter foraging strategy (Skinner and Smithers 1990; Monadjim *et al*. 2010). Furthermore, both species differ to some degree in their preferences for prey. For example, *Pipistrellus rusticus* eats Diptera, which is not evident in the *Rhinolophus hilderbrandtii's* diet (Schoeman 2006, Altridge and Rautenbach 1987, Fenton *et al.* 1998b). This suggests that although a foraging ecology might explain the distribution of some species, it does not explain the distribution of others.

In general, *Mops midas* has a similar distribution to that of *Pipistrellus rusticus* and *Rhinolophus hilderbrandtii*. However, the probability of occurrence of *Mops midas* is more restricted northwards compared to the other two species, and is absent from the arid Kalahari region of the Savannah biome (see Figure 12, and Appendix 4g). The absence of *Mops midas* from the arid savannah could be linked to the influence of the second most influential variable on the distribution of this species, which is low temperature seasonality (about 15%). It appears that this species is sensitive to severe temperature fluctuations and therefore avoids areas with high temperature seasonality. Temperature is highly seasonal in the arid savannah including the Kalahari region where the temperature in summer is much higher than in winter. For example, average midsummer maximum temperatures exceed 35 ºC in January and the lowest average minimum midwinter temperature is approximately 2.5 ºC in July (Mares 1999). The predicted distribution of this species in the mesic regions of the Savannah biome in the northeastern tip of South Africa is supported by the literature (Skinner and Smithers 1990; Monadjem *et al*. 2010).

Unlike the three bat species that were influenced similarly by precipitation seasonality, *Eidolon helvum* was influenced differently by this variable and demonstrated a different predicted probability of occurrence compared to the other three species (see Figure 11, and

Appendix 4e). This species showed a preference for relatively lower precipitation seasonality (60-70%) compared to the other three species which preferred higher precipitation seasonality (90-100%). Although rain could fall in any month in the Free State Province (i.e., where a high probability of occurrence is predicted for this species), most of the rain usually falls in summer during the months of February and March (Howell 1978). However, if precipitation seasonality is the tendency in an area, that is, more rainfall is experienced in particular months or seasons (Markham 1970), the Free State Province (in the Grassland biome) would be expected to have a lower rainfall seasonality compared to the Savannah biome in the northeast of South Africa. The average rainfall in the Free State Province is approximately 400 mm in summer and 150 mm in winter (Gbetibouo and Hassan 2005). However, the distribution of this species in other parts of Africa supports the findings of the current study, that is, it prefers low seasonality in precipitation, although not necessarily so. For example, four radio-tracked individuals from the Kansanka colony in Zambia revealed that this species undertakes long distance migration on a large scale involving millions of individuals (Richter and Cumming 2008). This suggests that *Eidolon helvum* might be tracking seasonal fruiting phenology of trees in the region, which could be correlated with rainfall patterns. Fruiting phenology of trees in the arid, semi-arid and mesic parts of South Africa differ between seasons. Immature fruits were found approximately two months after the appearance of buds and flowers, peaking in March (the peak rainy season in the Free State Province where a high probability of occurrence is predicted for *Eidolon helvum*). However, certain fruits were found throughout the year, but with the lowest levels occurring from July to October (the dry season in the summer rainfall regions of South Africa) (Shackleton 1999).

While there is no large-scale fruit cultivation in the Free State, small-scale fruit farming exists; for example, apple farming in the Bethlehem apple project as well as grape farming in the Jacobsdal scheme (Stevens 2007). However, there are other areas in South Africa with more intensive fruit farming, for example, The Cape Floristic Region (Rouget *et al.* 2003), and other areas with enough natural fruit to support other fruit eating bat species, for example, the afromontane forests in KwaZulu-Natal (Wirminghaus *et al.* 2001b), yet *Eidolon helvum* does not occur there. A possible explanation for this could be that the predicted distribution of this species is probably an artefact of very few locality records in the southern limits of a species that has a more extensive distribution in the tropics of Africa and does not breed in South Africa but only appears in South Africa as a vagrant.

The distribution of two South African rhinolophids species, *Rhinolophus blasii* and *Rhinolophus simulator* (see Table 5) is associated with precipitation in the warmest quarter. This suggests that both species are adapted to inhabit a subtropical climate (the Savannah biome) with a warm summer (November–March), where the amount of precipitation in the warmest three months of the year (summer) is approximately 600 mm. In addition, the two species appear to coexist in their distributional range as well as their predicted probability of occurrence in the Savannah biome in the Limpopo and KwaZulu-Natal Provinces of South Africa (see Figures 15, and 16). Sympatry between these two species might be linked to their dietary resemblance and overlap. Findley and Black (1983) reported that diet of *Rhinolophus blasii* and *Rhinolophus simulator* in Zambia consisted mostly of Lepidoptera (96.9% and 72.9% during summer and 87.2% and 100%) during winter months, respectively. Dietary overlap between the two species was 80.1% in Zambia (Findley and Black 1983). In South Africa, the diet of *Rhinolophus blasii* consisted mostly of Lepidoptera (82.1%), Coleoptera (6.7%) and Hemiptera (5.70%) in the Savannah biome (Schoeman and Jacobs 2011). However, for *Rhinolophus simulator*, Jacobs (2000) reported that the diet of this species constituted mostly of Lepidoptera (65.5) during summer months in the Savannah biome. The importance of precipitation in the warmest quarter for these species might be through the influence of precipitation on their diet. There is some evidence, although little, of the correlation between the distribution and abundance of aerial arthropods and precipitation of the warmest months in South Africa. For example, in the Kruger National Park (Mpumalanga) the peak monthly occurrence of aerial arthropods correlates with the warm summer rainy season (Rautenbach *et al.* 1988). In addition, long term monitoring of *Busseola fusca* (Order Lepidoptera) in Mpumalanga Province (in the Savannah biome) of South Africa illustrated that the first flight of hibernating moths emerging from borers was the highest in mid November (i.e., summer) (Kfir and Bell 1993; Kfir 2000). In addition, the second and third flights of moths were the highest in mid-February and mid-April (i.e., summer months) respectively (Kfir and Bell 1993; Kfir 2000). In their study, flights of moths were not recorded during winter (June–September).

The distribution of only one South African bat species; *Neoromicia melckorum* (see Table 5) was found to be associated with precipitation of the coldest quarter as the most important predictor variable. This species appears to prefer the Mediterranean climate of the winter rainfall region in the Fynbos biome of South Africa where precipitation in the coldest three

months of the year is between 150 and 450 mm (see Appendix 4r). This result supports the ecological notes on this species, as Monadjem *et al*. (2010) stated that individual records for this species exist for the southwestern parts of South Africa. However, there is a data point for *N. melckorum* in the far northeast of South Africa that appears to be in a low probability area (Figure 17). This could be an erroneous record for this species because of misidentification or it could be a record of a vagrant individual. There is no information on the ecology of this species in South Africa. Therefore, it is difficult to speculate regarding explanations for why this species prefers the precipitation (150 mm to 400 mm) in the coldest quarter (see Figure 17).

In general, measures of precipitation (annual precipitation) appear to be the limiting factor for fruit bats in South Africa, probably through the influence of annual rainfall on fruiting plants. In addition, annual precipitation influences insectivorous bats that are widely distributed and their distribution patterns show a clear decreasing trend from east to west similar to the mean annual precipitation in South Africa. Furthermore, annual precipitation also influences bats that can tolerate more arid conditions in South Africa. On the other hand, a measure of seasonality in precipitation (precipitation seasonality) seems to restrict the distribution of bats that inhabit the subtropical biomes of South Africa (i.e., the Savanna and Grassland biomes). Finally, measures of extreme precipitation variables (precipitation of the warmest and coldest quarters) appear to influence bat species that inhabit mesic parts of South Africa including the Savannah biome in the eastern and northeastern parts of South Africa and the Fynbos biome in the Western Cape Province. The influence of extreme precipitation variables on bats might be linked to their influence on the abundance of insects, which constitutes the diet of these bat species.

4.5 Temperature

Contrary to the thesis predictions, extreme temperature variables appeared to have a significant influence on the distribution of bats in South Africa, despite temperature ranges being relatively smaller in South Africa than elsewhere in the world. Temperature variables appeared as the most important factor influencing the distribution of 12 of the 37 species of bats included in this study (see Table 6) and the second most important factor in five

additional species (see Tables 5 and 7). Thus the distributions of 15 of the 37 species were influenced by temperature in one form or another (see tables 5, 6, and 7).

The importance of temperature to the distribution of South African bats (see Table 6) might be linked directly to roosting ecology and the thermoregulation capability of each species and their need for hibernation and/or torpor to save energy in times of food scarcity. This is in line with prior studies elsewhere that have indicated that temperature parameters are one of the main determinants of bat distribution patterns in China (Li *et al.* 2005), Mexico (Wang *et al.* 2003), and Israel (Yom-Tov and Kadmon 1998). Most temperature variables used in these studies were also considered in the current study. Despite temperature ranges being smaller in South Africa than in these countries, temperature was nevertheless still a factor influencing the distribution of bats in South Africa. The average range in annual temperatures is about 17°C in Cape Town in the south-west and 17.5°C in Pretoria in the north-east of South Africa. The average annual temperatures are about 6.6–22.4°C between the north-east and southern China (Veeck *et al.* 2011); Mexico, 15°C in areas at 2,440m (a.s.l) and a permanent snow above 4,000 m (a.s.l) (Encyclopaedia Britannica 2011); Israel, l7°C–25°C at the Hills to the Jordan Valley (Orni and Efrat 1973). However, different temperature variables influenced the distribution of bats in different countries. For example, bat distributions were influenced by temperature trends (i.e., annual mean temperature) in China and temperature extremes in Mexico as well as in Israel.

Extreme measures of temperature (i.e., mean temperature of the coldest quarter) were the most important variables influencing the distribution of bats in South Africa. A mean temperature of about 19°C of the coldest quarter favoured the occurrence of all six species, while the lower limit varied between 4°C for *Mops condylurus* and *Epomophurus crypturus*, 5°C for *Scotophilus dinganii*, 6°C for *Chaerephon pumilus* and *Hipposideros caffer*, and 13°C for *Scotophilus viridis* (see Appendices 4aa, 4af, 4t, 4y, 4ac, and 4w). All six bat species (see Table 6) have their distribution range east of the country extending northwards towards KwaZulu-Natal and northern South Africa (see Figures 18, 19, 20, 21, 22, and 23). Interestingly, a high probability of occurrence for all six species was predicted in the Mopane veld and the lowveld regions of South Africa (Figures 18, 19, 20, 21, 22, and 23). It is possible that bat species in this group are limited by a low mean temperature of the coldest quarter of the year mainly because their roost microclimates are unpredictable and change as

daily weather conditions change. This situation might prevent them from entering deep torpor as reported for other mammalian taxa (Jackson *et al.* 2009). Temperature within tree-cavity roosts might oscillate broadly depending on the thermal insulation properties of the tree structure (Humphrey *et al.* 1977; Körtner and Geiser 2000b). The use of trees to some extent as a roosting site, is a common attribute among all six species; *Scotophilus dinganii* and *Scotophilus viridis* (Jacobs *et al.* 2007b, Jacobs and Barclay 2009), *Chaerephon pumilus* (Verschuren 1957a), *Mops condylurus* (Fenton *et al.* 1994), *Hipposideros caffer* (Wright 2009) and *Epomophorus crypturus* (Monadjem *et al.* 2010). Some of these tree-roosting bats are known to enter torpor in South Africa. For example, *Mops condylurus* is capable of entering torpor at times of the lowest ambient temperatures (i.e., between 6:00 and 10:00 in the morning) in the Mpumalanga Province of South Africa (Vivier and van der Merwe 2007). In addition, *Scotophilus dinganii* has been reported entering torpor in the KwaZulu-Natal Province of South Africa (Jacobs *et al.* 2007b). For the remaining four species of bats in this group, there is a lack of research in South Africa concerning this topic. Further research is therefore required regarding the thermoregulatory and roosting behaviour of bats in South Africa.

The distribution of *Nycteris thebaica* and *Neoromicia nana* is associated with the minimum temperature of the coldest month (see Table 7). A minimum temperature of about 12.5 °C of the coldest month favoured the occurrence of both species while the lower limit varied between (≥ -4°C) for *Neoromicia nana* and (0°C) for *Nycteris thebaica* (see Appendices 4aq, and 4an). The locality records for *Nycteris thebaica* indicates that this species is widely distributed, while the distribution of *Neoromicia nana* is restricted to the eastern and northern parts of South Africa where the distribution range of the two species overlap (see Figures 25, 27). The distribution pattern predicted for *Neoromicia nana* in the current study conforms with reports in literature that this species has a geographical range that extends extensively into Africa but is restricted to non-arid areas south of the Sahara (Bernard *et al*. 1997; Taylor 2000). The restricted distribution range of *Neoromicia nana*, in spite of its being able to withstand colder temperatures compared to *Nycteris thebaica*, appears to be linked to the distribution of banana plantations. Furled leaves of banana plants and the perennial *Strelizia* spp. are the main roosts of *Neoromicia nana* in South Africa and elsewhere in Africa (see Rosevear 1965, La Val and La Val 1977, Monadjem and Fahr 2007). Chiropterans spend a considerable amount of time throughout their lives roosting (Kunz 1982); the existence of

suitable roosts are crucial for their survival (Humphrey 1975; Fenton 1983). However, the availability, distribution and suitability of roosts may change throughout the year (Lott 1991), especially for bats. Roosting requirements for *Neoromicia nana* include banana leaves, the leaves of other plants, and roofs made of thatch or palm leaves (Rosevear 1965, Monadjem and Fahr 2007). *Neoromicia nana* uses banana leaf tubes as a roost for a few days; thereafter, it has to fly around South Africa in search of suitable leaf tubes throughout the rest of the year (La Val and La Val 1977; van der Merwe and Stirnemann 2009). Commercial banana plantations are generally distributed in the subtropical coastal regions of South Africa, from the south coast of KwaZulu-Natal in the east to the Mpumalanga Province in the northeast (see Karamura *et al.* 1998; De Graaf *et al.* 2005; van den Berg *et al.* 2007).

Nycteris thebaica, on the other hand, is a roost generalist and uses a variety of roost types, which appear to be abundant throughout the year, compared to the roosts of *Neoromicia nana*. *Nycteris thebaica* roosts during the day in half-dark and shallow caves, aardvark (*Orycterops afer*) burrows, culverts under roads and the trunks of large trees (Monadjem *et al.* 2009).
The distribution of only one South African bat species, *Miniopterus fraterculus* (see Table 6) was found to be associated with an annual range in temperature as the most important predictor variable and that preferred an annual range of between 13 and 18°C (see Appendix 4at). The predicted distribution of this species extends from KwaZulu-Natal northwards towards Mpumalanga and parts of the Limpopo Province and covers mostly the lowveld region of the Savannah biome (Figure 28). This species appears to be able to tolerate only small fluctuations in temperature throughout the year. This agrees with its distribution in the lowveld region of South Africa, where the annual range in temperature is (16-27°C) (Encyclopaedia Britannica 2011) which is within the preferred range of temperature for this species. The current results on the predicted distribution of this species in South Africa is in agreement with the findings of Monadjem *et al.* (2010), although their statement that 'the core distribution of this species is in the montane grassland of South Africa' seems to be in contrast with the results of the current study. Rather, the predicted distribution as well as the presence records of this species suggest that their distribution range extends from the Lowveld in the south of its range to the Highveld (temperate grassland) in the north.

The distribution of only one South African bat species, *Nycticeinops schlieffeni* (see Table 6), was found to be associated with an annual mean temperature as the most important predictor

variable and preferred a mean annual temperature of about 24°C and appears to be limited by a mean annual temperature not lower than 17°C (see Appendix 4aw). Verschuren (1957a) stated that this species roosts in crevices in trees and in houses (Rosever 1965). However, there are two data points for *N. schlieffeni* that are located in low probability areas (Figure 29). This could be a result of misidentification or records of vagrant individuals. The distribution of this species is marginal in South Africa which represents the southern limit of its distribution. It is therefore difficult to give concrete explanations as to why this species is influenced by annual mean temperature. As in the case of *Edolon helvum* whose distribution is marginal in South Africa, the predictive model in this study used only a small part of the distributional range of that of *Nycticeinops schlieffeni*. This could constitute one of the potential problems that could arise when using political boundaries to delimit the study of animal distributions.

4.6 Potential caveats of the current study

There are several caveats that should be considered when drawing conclusions from the data presented here. The majority of the environmental variables used in this study to model the distribution of bats, were correlated to some degree. Correlation between variables could influence the effect that any one environmental variable has on model performance and could lead to erroneous conclusions about which of the correlated variables are in fact important. This was probably the case of *Rhinolophus capensis* in the current study in which the model predicted that the distribution of this species was most influenced by biome, which might not be the case. Rather, the amount of precipitation in the coldest quarter of the year could be the main variable influencing the distribution of *Rhinolophus capensis*. All biomes predicted as being important for this species fall within the winter rainfall region of South Africa. Precipitation of the coldest quarter of the year (i.e., the winter months) might therefore be correlated with biomes. To alleviate the problem of correlated variables, only one variable was selected from a set of highly correlated variables in case of positive ($r \geq 0.7$) or negative ($r \leq -0.7$) correlations for inclusion in the models, as suggested by Kumar and Stohlgren (2009). However, this did not entirely alleviate the problem of correlated variables as the example of *Rhniolophous capensis* suggests. This renders the identification of several

environmental factors, as carried out here, rather than just one, important for investigation into the mechanisms by which these factors limit the distributions of species.

Another problem concerns data completeness. Milne *et al.* (2006) indicated that database systems for some institutions (e.g., museums) mostly do not include some of the important information such as the activity of a particular individual species at the time of detection or collection in the field. Consequently, in the case of bats, it becomes difficult to know whether bats were foraging or roosting when they were detected or recorded (Milne *et al.* 2006) and/or collected as voucher specimens. Behavioural information is essential for explaining the results of a study based on field observations, especially for volant taxa such as bats that can commute long distances from their roosts to reach their foraging habitats (Lumsden *et al.* 2002; Law and Chidel 2004). If roosting and foraging habitats are different, and if field records are obtained from the same species at roost sites as well as foraging areas, the models might fail to interpret the results from the two habitats separately (Milne *et al.* 2006). This could lead to erroneous conclusions about the factors that limit the distributions of organisms.

Furthermore, data of presence records for South African bats that were used to build the MaxEnt models for this study covered a long period of time (i.e., some presence records dated back to the early 1900s) which have not taken into account potential changes in environmental variables or bat populations since that period. For example, Mills and Hes (1997) noted that *Cloeotis percivali* (one of the species included in this study) is no longer present in certain areas within South Africa where it was found 50 or more years ago. However, the authors did not mention the names of the localities where the species are no longer present. Similar concerns have been raised in the literature concerning species distribution models (Braithwaite and Griffiths 1994; Woinarski *et al.* 2001; Pardon *et al.* 2003). However, Milne *et al.* (2006) suggested that such species distribution models and their resultant predicted probability of occurrence maps should be considered as 'maximum-likelihood' models and must be used with caution. Modelling outcomes are hypothetical and it is therefore important that the results of such modelling, including the models presented in the current study, be verified through field observations in areas that show a high probability of occurrence for a particular species, but which were not sufficiently sampled at the time of modelling.

A problem peculiar to the current study in which the area of focus was demarcated by a political boundary (for tractability) is that the distribution ranges of certain bat species have their centres of distribution further north in Africa and only have marginal intrusion into the political boundaries of South Africa (Gelderblom *et al.* 1995); for example, *Rhinolophus denti, Eidolon helvum* and *Nycticeinops schlieffeni* all have marginal distributions in South Africa. This entails using only a portion of a species distribution range in modelling that could give erroneous results that might not be transferable to other parts of the species range. In addition, the use of political boundaries when modelling the distributions of species could lead to arbitrary division of the distribution ranges of a species that are meaningless from a species perspective. It is possible that the MaxEnt models from this study could have provided results that are unrealistic for species that have their core distributions further north in Africa. Inclusion of these species was necessary to make the exercise more tractable; however, the results for such species could be viewed as a point of departure for future studies.

Lastly, using environmental variables that are segmented into too many detailed parts, like the ones that are used in this study, cause redundancy among these environmental variables that may lead to erroneous model predictions. For example, Beaumonta *et al.* (2005) examined how the splitting up of different environmental variables affects model accuracy in BIOCLIM (i.e., a correlative modelling technique like MaxEnt). They predicted the current distributions of 25 Australian butterfly species by using three different methods of selecting climatic parameters: 1) all of the 35 environmental variables; 2) arbitrary selection of the most relevant variables for individual species; and 3) a subset of eight variables that may generally influence the distributions of butterflies. Their main results show that the extent of predicted distributions was negatively correlated with the number of variables included in the model. However, there were no significant differences in the relative change in the predictive distribution range size between the three methods. For the current study, this situation was not relevant as the MaxEnt built-in Jackknife test was used to eliminate variables that contribute less to the model performance.

4.7 Potential effects of future climate change on the distribution of South African bat species

Large-scale changes in the distribution and abundance of various taxa have been witnessed in recent decades because of human-induced climate change (Parmesan and Yahe 2003; Root *et al.* 2003). Therefore, proper investigations of the key correlates of climate change (i.e., temperature and precipitation (Walther *et al.* 2002; Parmesan and Yohe 2003) as well as changes in ecosystems (Vitousek *et al.* 1997; Jones *et al.* 2009)) are essential actions prior to pursuing any preventive measures of climate-change. Climate change effects on terrestrial and aquatic ecosystems have been determined for several regions around the planet, including South Africa (Leemans and Eickhout 2004; Nkomo *et al.* 2006; Warren *et al.* 2006). Responses of South African biomes to climate change scenarios suggested a high vulnerability of the Succulent Karoo to high end warming scenarios for the year 2100 (mean 5.5°C above current ambient temperature), and this increase in temperature could cause certain succulent plant species to disappear (Musil *et al.* 2005). In addition, a reduction in a distribution range of between 4 to 98 percent has been projected for 80 percent of savannah and grassland animal species in South Africa under a 'business-as-usual' type emissions scenario (IS92a), which presumes a public policy that does not consider climate-change concerns (Erasmus *et al.* 2002). Furthermore, the endemic protea species in the Mediterranean-climate region of South Africa might face an extinction risk from both climate change as well as land-use changes by 2020 (Bomhard *et al.* 2005).

In light of the potential influence of climate change on South African ecosystems and species, the South African bat species will probably face similar consequences. We would expect 80 percent of savannah and grassland bat species in South Africa to undergo a severe distribution range decline similar to that described in the study conducted by Erasmus *et al.* (2002) on South African mammals. The current study confirmed that 12 (37.5%) out of 32 species of South African bats whose predicted distribution included the Savannah biome responded to temperature parameters as being the most important variable influencing their distribution. Among the 12 South African bat species influenced mostly by temperature variables, 3 are of conservation importance, *Kerivoula lanosa* and *Miniopterus fraterculus* is near threatened, and *Rhinolophous swinnyi* is endangered, according to the World Conservation Union

(IUCN) (Friedmann and Daly 2004). Interestingly, this study illustrated that the distribution ranges of the *Rhinolophus swinnyi* and *Kerivoula lanosa* were influenced by a narrow window of temperature seasonality; in fact they were limited by a temperature seasonality of ≥15 percent and ≥18 percent, and favoured a temperature seasonality of <15 percent and <18 percent, respectively throughout the year. Consequently, this will make them vulnerable to severe climate change effects under the high-end warming scenarios for 2100 as the mean ambient temperature increases to 5.5°C above the current level. Additionally, *Miniopterus fraterculus*, which appeared to prefer an annual range in temperature of between 13 and 18°C, and is limited by an annual range in temperature of >18°C, could also be influenced negatively under the high-end warming scenarios for 2100.

However, projections for the rainfall effect on South African taxa as a correlate of climate change are tricky, as there is no clear long-term trend for rainfall in the region except for post-1970, which indicated higher rainfall trends as well as severe droughts (Rhichard *et al.* 2001, Fauchereau *et al.* 2003). The combined effects of future climate and land use changes on South African bats are a complex issue that need additional modelling combined with a greater understanding of the biology of bat species. The latter would provide the information needed to understand the factors identified as limiting the distributions of species and/or causing their ranges to contract. Inadequate knowledge of the natural history and ecology of most of the bat species in South Africa makes it difficult to interpret how or why certain environmental factors limit the distribution of each bat species. Much more research is thus required regarding the ecology of African bat species.

In conclusion, bat species in South Africa seem to be influenced by a variety of environmental variables including biophysical (geology, land use/land cover, and biome), precipitation, and temperature variables. In order of significance, according to the number of bat species influenced by each variable, geology and precipitation were equally the most important variables followed by temperature and land use/land cover. Biome was the least important among the variables modelled. Geology appears to be the most important or the second most important limiting factor for 19 of the 37 species, 15 of which are known to use roosts associated with geological features (i.e., caves, mines, and rock crevices). Precipitation variables appear as being the most important or the second most important factor influencing the distribution of 19 of the 37 species of bats. Most of them have their distribution ranges

centred towards the east or northeast of South Africa. The influence of precipitation on South African bats is probably related to its effect on the availability of food in the form of fruit or insects. Temperature variables appear to be the most important or the second most important factors that influence the distribution of 15 of the 37 species of bats and might be linked directly to roosting ecology and thermoregulation capabilities of these species as well as their need for hibernation and/or torpor. Biome appears to be the most important variable influencing the distribution of only one South African bat species, the endemic *Rhinolophus capensis*, while none of the South African bat species distributions were influenced by biome as being the second most important variable.

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APPENDICES

Appendix 1

Model selection for South African bat species considered for analysis in MaxEnt based on average AUC (n = 10) scores, for test and training data, and the AUC p-values and Mann-Whitney Z scores, for the training data, associated with the comparison of each simplified model with the larger model with one more variable therein. The last column furnishes the predictor variables removed from the previous larger models starting from the full model for *Epomophorus wahlbergi*. The bold font indicates the best model selected.

Appendix 1a. *Rhinolophus clivosus*.

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
9	0.722	0.82			
8	0.724	0.82	0.94	0.08	Isothermality
7	0.725	0.82	0.31	1.02	Maximum temperature of warmest month
6	0.721	0.81	0.34	0.94	Precipitation of driest quarter
5	0.720	0.81	0.24	1.17	Temperature annual range
4	0.723	0.81	0.43	0.79	Elevation
3	0.724	0.80	0.27	1.10	Biome
2	**0.720**	**0.78**	**0.026**	**2.23**	**Land use/Land cover**
1	0.709	0.71	0.0002	3.74	Geology (i.e., with only annual precipitation)

Appendix 1b. *Pipistrellus hesperidus*.

Number of variables per model	Average test AUC	Average training AUC	P-value	Z-score	Predictor variable removed
10	0.90	0.97			
9	0.90	0.97	0.94	-0.08	Temperature annual range
8	0.90	0.97	0.94	0.08	Isothermality
7	0.91	0.97	0.94	-0.08	Temperature seasonality
6	0.91	0.97	0.76	0.30	Mean temperature of coldest quarter
5	0.91	0.96	0.43	0.79	Precipitation of coldest quarter
4	0.92	0.96	0.38	0.87	Geology
3	0.91	0.95	0.36	0.91	Maximum temperature of warmest month
2	**0.89**	**0.94**	**0.04**	**2.01**	**Biome**
1	0.92	0.91	0.004	2.91	Land use/Land cover (with only annual precipitation)

Appendix 1c. *Eidolon helvum.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
12	0.67	0.92			
11	0.67	0.92	1.00	0.00	Mean temperature of wettest quarter
10	0.67	0.91	0.60	0.53	Mean temperature of warmest quarter
9	0.67	0.91	0.71	0.38	Mean temperature of coldest quarter
8	0.68	0.91	0.97	-0.04	Mean temperature of driest quarter
7	0.68	0.92	0.71	-0.38	Isothermality
6	0.67	0.91	0.34	0.94	Precipitation of coldest quarter
5	0.67	0.90	0.38	0.87	Biome
4	0.68	0.89	0.08	1.78	Maximum Temperature of warmest month
3	0.70	0.86	0.006	2.76	Geology
2	**0.74**	**0.86**	**0.38**	**0.87**	**Land use/Land cover**
1	0.70	0.79	0.0002	3.74	Precipitation of warmest quarter (i.e., with only precipitation seasonality)

Appendix 1d. *Mops midas.*

Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
9	0.93	0.97			
8	0.93	0.97	1.00	0.00	Isothermality
7	0.93	0.97	1.00	0.00	Precipitation of wettest month
6	0.93	0.97	1.00	0.00	Biome
5	0.93	0.97	0.88	-0.15	Mean temperature of coldest quarter
4	0.92	0.97	0.62	0.49	Precipitation of coldest quarter
3	0.94	0.96	0.009	2.60	Geology
2	**0.92**	**0.95**	**0.006**	**2.76**	**Land use/Land cover**
1	0.86	0.89	0.0002	3.74	Temperature seasonality (i.e., with only precipitation seasonality)

Appendix 1e. *Pipistrellus rusticus.*

Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
7	0.89	0.96			
6	0.89	0.96	0.97	0.04	Precipitation of warmest quarter
5	0.90	0.95	0.19	1.32	Annual mean temperature
4	0.90	0.95	0.50	-0.68	Biome
3	**0.89**	**0.95**	**0.31**	**1.02**	**Temperature seasonality**
2	0.90	0.94	0.001	3.21	Land use/Land cover
1	0.86	0.90	0.0002	3.74	Geology (i.e., with only precipitation seasonality)

Appendix 1f. *Rhinolophus hildebrandtii*.

Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
7	0.89	0.97			
6	0.89	0.97	0.97	-0.04	Isothermality
5	0.89	0.97	0.79	0.26	Mean temperature of coldest quarter
4	0.91	0.97	0.91	0.11	Biome
3	0.91	0.96	0.14	1.47	Land use/Land cover
2	**0.88**	**0.94**	**0.045**	**2.00**	**Precipitation of warmest quarter**
1	0.85	0.88	0.0003	3.59	Geology (i.e., with only precipitation seasonality)

Appendix 1g. *Rhinolophus blasii.*

Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
7	0.80	0.94			
6	0.80	0.94	1.00	0.00	Mean temperature of coldest quarter
5	0.892	0.94	0.88	0.15	Biome
4	0.79	0.93	0.23	1.14	Temperature seasonality
3	0.80	0.91	0.08	1.78	Precipitation seasonality
2	**0.83**	**0.89**	**0.08**	**1.78**	**Land use/Land cover**
1	0.62	0.85	0.045	2.01	Precipitation of warmest quarter (i.e., with only geology)

Appendix 1h. *Rhinolophus simulator*.

Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
7	0.89	0.94			
6	0.89	0.93	0.62	0.49	Isothermality
5	0.90	0.93	0.91	0.11	Temperature seasonality
4	0.89	0.93	0.33	0.98	Biome
3	0.90	0.92	0.24	1.17	Mean temperature of coldest quarter
2	**0.90**	**0.91**	**0.038**	**2.08**	**Land use/Land cover**
1	0.87	0.87	0.0002	3.67	Geology (i.e., with only Precipitation of warmest quarter)

Appendix 1i. *Neoromicia melckorum.*

Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
13	0.80	0.92			
12	0.80	0.92	0.96	0.04	Annual mean temperature
11	0.80	0.92	0.94	0.08	Precipitation of driest month
10	0.80	0.92	0.65	0.45	Mean temperature of driest quarter
9	0.80	0.92	0.82	0.23	Isothermality
8	0.81	0.91	0.79	0.26	Biome
7	0.81	0.91	0.96	0.04	Temperature annual range
6	0.81	0.91	0.47	0.72	Precipitation seasonality
5	0.80	0.91	0.71	-0.38	Elevation
4	0.84	0.88	0.003	2.99	Geology
3	0.85	0.87	0.045	2.00	Land use/Land cover
2	**0.85**	**0.82**	**0.005**	**2.83**	**Mean temperature of wettest quarter**
1	0.82	0.77	0.004	2.9	Precipitation of warmest quarter (i.e., with only Precipitation of coldest quarter)

Appendix 1j. *Scotophilus dinganii.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
8	0.88	0.93			
7	0.88	0.93	0.5	0.68	Mean temperature of wettest quarter
6	0.88	0.92	0.45	0.76	Isothermality
5	0.88	0.92	0.47	0.72	Precipitation seasonality
4	0.88	0.92	0.2	1.29	Biome
3	**0.88**	**0.91**	**0.005**	**2.83**	**Geology**
2	0.89	0.90	0.0009	3.33	Land use/Land cover
1	0.84	0.85	0.0002	3.74	Precipitation of warmest quarter (i.e., with only mean temperature of coldest quarter)

Appendix 1k. *Scotophilus viridis.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
6	0.94	0.97			
5	0.94	0.97	0.97	0.04	Isothermality
4	0.94	0.97	0.97	0.04	Biome
3	0.94	0.97	0.91	-0.11	Precipitation of warmest quarter
2	**0.98**	**0.95**	**0.002**	**3.14**	**Land use/Land cover**
1	0.98	0.92	0.002	3.06	Geology (i.e., with only mean temperature of coldest quarter)

Appendix 1l. *Chaerephon pumilus.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
10	0.94	0.96			
9	0.94	0.96	1.00	0.00	Mean temperature of driest quarter
8	0.94	0.96	0.91	0.11	Temperature seasonality
7	0.94	0.96	0.57	0.57	Biome
6	0.94	0.96	0.23	1.2	Diurnal temperature range
5	0.94	0.96	0.1	1.63	Precipitation of driest quarter
4	0.94	0.95	0.02	2.34	Isothermality
3	0.94	0.95	0.1	1.63	Land use/Land cover
2	**0.94**	**0.93**	**0.002**	**3.06**	**Geology**
1	0.91	0.90	0.002	3.06	Precipitation of warmest quarter (i.e., with only mean temperature of coldest quarter)

Appendix 1m. *Mops condylurus.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
9	0.93	0.98			
8	0.93	0.98	0.82	0.23	Temperature seasonality
7	0.93	0.98	0.85	0.19	Precipitation of warmest quarter
6	0.93	0.98	0.55	0.6	Biome
5	0.93	0.98	0.71	0.38	Mean temperature of warmest quarter
4	0.93	0.97	0.16	1.4	Isothermality
3	0.91	0.97	0.50	0.68	Precipitation of coldest quarter
2	**0.93**	**0.97**	**0.15**	**1.44**	**Land use/Land cover**
1	0.93	0.94	0.002	3.06	Geology (i.e., with only mean temperature of coldest quarter)

Appendix 1n. *Hipposideros caffer.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
9	0.93	0.96			
8	0.93	0.96	0.85	0.19	Isothermality
7	0.93	0.96	0.82	0.23	Temperature seasonality
6	0.93	0.96	0.54	0.61	Mean temperature of wettest quarter
5	0.93	0.96	0.79	0.26	Temperature annual range
4	0.93	0.96	0.71	0.38	Biome
3	**0.93**	**0.95**	**0.01**	**0.25**	**Land use/Land cover**
2	0.93	0.94	0.002	2.99	Geology
1	0.91	0.92	0.0002	3.74	Precipitation of warmest quarter (i.e., with only mean temperature of coldest quarter)

Appendix 1o. *Epomophorus crypturus.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
9	0.94	0.97			
8	0.94	0.97	0.97	0.04	Temperature annual range
7	0.94	0.97	1.00	0.00	Temperature seasonality
6	0.94	0.97	1.00	0.00	Precipitation seasonality
5	0.95	0.97	0.94	0.08	Isothermality
4	0.95	0.97	0.15	1.45	Geology
3	0.94	0.96	0.03	2.16	Biome
2	**0.92**	**0.94**	**0.08**	**1.78**	**Precipitation of warmest quarter**
1	0.92	0.90	0.01	2.54	Land use/Land cover (i.e., with only mean temperature of coldest quarter)

Appendix 1p. *Rhinolophus swinnyi*.

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
10	0.9 0	0.98			
9	0.90	0.98	0.97	0.04	Precipitation of driest quarter
8	0.90	0.98	1.00	0.00	Temperature annual range
7	0.90	0.98	1.00	0.00	Annual precipitation
6	0.92	0.98	0.76	0.03	Minimum temperature of coldest month
5	0.91	0.98	0.96	-0.04	Precipitation of warmest quarter
4	0.92	0.98	0.62	0.49	Isothermality
3	0.92	0.98	0.41	0.83	Biome
2	**0.94**	**0.97**	**0.004**	**2.91**	**Land use/Land cover**
1	0.91	0.91	0.0002	3.74	Geology (i.e., with only temperature seasonality)

Appendix 1q. *Kerivoula lanosa.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
10	0.84	0.99			
9	0.84	0.99	1.00	0.00	Precipitation of driest quarter
8	0.84	0.99	1.00	0.00	Precipitation of warmest quarter
7	0.84	0.99	1.00	0.00	Annual precipitation
6	0.84	0.99	1.00	1.00	Elevation
5	0.84	0.99	0.68	0.42	Isothermality
4	**0.84**	**0.99**	**0.76**	**0.31**	**Minimum temperature of coldest month**
3	0.87	0.97	0.001	3.21	Land use/Land cover
2	0.88	0.96	0.002	3.02	Biome
1	0.90	0.90	0.0002	3.74	Geology (i.e., with only temperature seasonality)

Appendix 1r. *Nycteris thebaica.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
12	0.72	0.82			
11	0.72	0.82	0.73	0.34	Annual precipitation
10	0.72	0.82	0.85	-0.19	Mean temperature of driest quarter
9	0.72	0.82	0.73	0.34	Precipitation of driest quarter
8	0.72	0.82	0.43	0.79	Mean temperature of wettest quarter
7	0.72	0.81	0.19	1.32	Mean temperature of warmest quarter
6	0.72	0.81	0.24	1.17	Biome
5	0.73	0.80	0.21	1.25	Isothermality
4	0.72	0.79	0.16	1.4	Precipitation of coldest quarter
3	**0.71**	**0.77**	**0.003**	**2.99**	**Precipitation of wettest quarter**
2	0.70	0.75	0.0003	3.59	Land use/Land cover
1	0.70	0.70	0.0002	3.74	Geology (i.e., with only minimum temperature of coldest month)

Appendix 1s. *Neoromicia nana.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
9	0.94	0.97			
8	0.94	0.97	0.94	0.08	Precipitation of driest month
7	0.94	0.97	0.62	0.49	Biome
6	0.94	0.97	0.32	0.98	Isothermality
5	0.94	0.96	0.36	0.91	Temperature seasonality
4	0.94	0.96	0.24	1.17	Precipitation of driest quarter
3	**0.94**	**0.96**	**0.52**	**0.64**	**Land use/Land cover**
2	0.95	0.95	0.001	3.21	Geology
1	0.93	0.92	0.0002	3.67	Precipitation of warmest quarter (i.e., with only minimum temperature of coldest month)

Appendix 1t. *Miniopterus fraterculus.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
11	0.88	0.97			
10	0.88	0.97	1.00	0.00	Isothermality
9	0.88	0.97	0.85	0.19	Precipitation of coldest quarter
8	0.88	0.97	0.68	0.42	Precipitation of driest quarter
7	0.88	0.97	0.73	0.34	Mean temperature of driest quarter
6	0.89	0.97	0.94	-0.08	Temperature seasonality
5	0.89	0.97	0.73	0.34	Annual precipitation
4	0.89	0.96	1.00	0.00	Biome
3	**0.89**	**0.96**	**0.27**	**1.1**	**Maximum temperature of warmest month**
2	0.88	0.94	0.001	3.40	Geology
1	0.88	0.90	0.0003	3.59	Land use/Land cover (i.e., with only temperature annual range)

Appendix 1u. *Nycticeinops schlieffeni.*

Number of variables per model	Average test AUC	Average training AUC	p-value	Z-score	Predictor variable removed
8	0.91	0.98			
7	0.91	0.98	0.85	0.19	Isothermality
6	0.91	0.98	0.85	-0.19	Biome
5	0.91	0.98	0.43	0.79	Precipitation of warmest quarter
4	0.91	0.98	1.00	0.00	Precipitation seasonality
3	0.92	0.98	0.024	1.17	Land use/Land cover
2	**0.90**	**0.96**	**0.02**	**2.31**	**Temperature seasonality**
1	0.90	0.94	0.014	2.43	Geology (i.e., with only annual mean temperature)

Appendix 1v. *Cistugo lesueuri.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
10	0.70	0.93			
9	0.70	0.93	0.94	-0.08	Precipitation of warmest quarter
8	0.70	0.93	1.00	0.00	Temperature annual range
7	0.70	0.93	0.97	0.04	Elevation
6	0.71	0.93	1.00	0.00	Mean temperature of wettest quarter
5	0.72	0.93	0.97	0.04	Precipitation of driest quarter
4	0.73	0.90	0.16	1.40	Biome
3	**0.74**	**0.90**	**0.94**	**0.08**	**Mean temperature of warmest quarter**
2	0.81	0.88	0.16	1.40	Mean temperature of coldest quarter
1	0.76	0.85	0.19	1.32	Land use/land cover (i.e., with only geology)

Appendix 1w. *Cloeotis percivali.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
10	0.88	0.96			
9	0.88	0.96	1.00	0.00	Precipitation seasonality
8	0.88	0.96	1.00	0.00	Temperature annual range
7	0.88	0.96	0.97	0.04	Mean temperature of coldest quarter
6	0.88	0.96	1.00	0.00	Precipitation of coldest quarter
5	0.88	0.96	1.00	0.00	Precipitation of warmest quarter
4	0.88	0.96	0.94	0.08	Temperature seasonality
3	**0.89**	**0.96**	**0.21**	**1.25**	**Biome**
2	0.85	0.93	0.02	2.31	Isothermality
1	0.73	0.93	0.68	0.42	Land use/Land cover (i.e., with only geology)

Appendix 1x. *Eptesicus hottentotus.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
11	0.75	0.93			
10	0.75	0.93	0.94	0.08	Minimum temperature of coldest month
9	0.75	0.93	0.94	0.08	Temperature annual range
8	0.76	0.93	0.85	0.19	Isothermality
7	0.76	0.93	0.76	0.30	Precipitation of warmest quarter
6	0.75	0.93	0.73	0.34	Mean temperature of driest quarter
5	0.67	0.91	0.34	0.94	Precipitation seasonality
4	0.67	0.90	0.34	0.94	Biome
3	0.67	0.88	0.08	1.78	Maximum temperature of warmest month
2	**0.68**	**0.88**	**0.73**	**0.34**	**Mean temperature of coldest quarter**
1	0.60	0.85	0.05	1.93	Land use/Land cover (i.e., with only geology)

Appendix 1y. *Miniopterus natalensis.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
12	0.72	0.82			
11	0.73	0.82	0.85	0.19	Mean temperature of driest quarter
10	0.73	0.82	0.68	0.42	Maximum temperature of warmest month
9	0.73	0.82	0.68	0.42	Precipitation of driest quarter
8	0.73	0.82	0.36	0.91	Temperature annual range
7	0.73	0.81	0.36	0.91	Isothermality
6	0.73	0.81	0.50	0.68	Mean temperature of wettest quarter
5	0.73	0.81	0.97	-0.04	Annual precipitation
4	0.73	0.81	0.16	1.40	Biome
3	**0.72**	**0.80**	**0.12**	**1.55**	**Mean temperature of coldest quarter**
2	0.67	0.76	0.0002	3.67	Precipitation of coldest quarter
1	0.64	0.71	0.0002	3.67	Land use/Land cover (i.e., with only geology)

Appendix 1z. *Myotis tricolor*.

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
11	0.78	0.93			
10	0.78	0.93	0.91	-0.11	Minimum temperature of coldest month
9	0.78	0.92	0.85	0.19	Mean temperature of driest quarter
8	0.78	0.92	0.65	0.45	Precipitation of coldest quarter
7	0.79	0.92	0.43	0.79	Isothermality
6	0.78	0.91	0.14	1.47	Annual precipitation
5	0.78	0.91	0.94	-0.08	Biome
4	0.80	0.90	0.13	1.51	Mean temperature of wettest quarter
3	**0.78**	**0.89**	**0.01**	**2.46**	**Diurnal temperature range**
2	0.72	0.86	0.002	3.14	Maximum temperature of warmest month
1	0.65	0.82	0.0003	3.59	Land use/Land cover (i.e., with only geology)

Appendix 1aa. *Rhinolophus darlingi.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
9	0.77	0.90			
8	0.77	0.90	0.88	0.15	Annual precipitation
7	0.77	0.90	0.45	0.76	Isothermality
6	0.78	0.90	0.73	0.34	Precipitation of coldest quarter
5	0.77	0.89	0.02	2.27	Precipitation seasonality
4	0.76	0.88	0.38	0.87	Mean temperature of coldest quarter
3	0.75	0.87	0.04	2.08	Biome
2	**0.76**	**0.86**	**0.14**	**1.47**	**Precipitation of wettest quarter**
1	0.72	0.83	0.001	3.21	Land use/Land cover (i.e., with only geology)

Appendix 1ab. *Sauromys petrophilus.*

Number of variables per model	Average Test AUC	Average training AU	P-value	Z-score	Predictor variable removed
10	0.78	0.94			
9	0.78	0.94	0.94	0.08	Temperature annual range
8	0.78	0.94	0.82	0.23	Annual mean temperature
7	0.79	0.93	0.62	0.49	Elevation
6	0.78	0.93	0.62	0.49	Annual precipitation
5	0.78	0.92	0.55	0.60	Isothermality
4	0.75	0.91	0.10	1.63	Mean temperature of driest quarter
3	0.71	0.89	0.12	1.55	Biome
2	**0.69**	**0.89**	**0.57**	**0.57**	**Precipitation seasonality**
1	0.71	0.86	0.03	2.16	Land use/Land cover (i.e., with only geology)

Appendix 1ac. *Rousettus aegyptiacus.*

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
10	0.82	0.97			
9	0.82	0.96	1.00	0.00	Mean temperature of driest quarter
8	0.82	0.96	0.60	0.53	Minimum temperature of coldest month
7	0.83	0.96	0.73	0.34	Isothermality
6	0.84	0.96	0.57	0.57	Precipitation of driest month
5	0.84	0.96	0.47	0.72	Temperature annual range
4	**0.84**	**0.94**	**0.004**	**2.87**	**Mean temperature of coldest quarter**
3	0.86	0.93	0.09	1.70	Land use/Land cover
2	0.87	0.89	0.0002	3.74	Geology
1	0.76	0.79	0.0002	3.74	Biome (i.e., with only annual precipitation)

Appendix 1ad. *Neoromicia capensis*.

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
10	0.60	0.70			
9	0.60	0.70	0.94	-0.08	Diurnal temperature range
8	0.60	0.70	0.88	0.15	Elevation
7	0.60	0.70	0.79	0.26	Temperature seasonality
6	0.60	0.70	0.82	0.23	Mean temperature of wettest quarter
5	0.60	0.70	1.00	0.00	Mean temperature of coldest month
4	0.60	0.70	1.00	0.00	Precipitation of wettest quarter
3	0.60	0.70	0.27	1.1	Precipitation of driest quarter
2	**0.60**	**0.70**	**0.21**	**1.25**	**Biome**
1	0.60	0.62	0.0002	3.74	Geology (i.e., with only land use/land cover)

Appendix 1ae. *Neoromicia zuluensis.*

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
11	0.91	0.97			
10	0.91	0.97	1.00	0.00	Minimum temperature of coldest month
9	0.91	0.97	0.76	-0.30	Precipitation seasonality
8	0.91	0.97	0.97	-0.04	Annual mean temperature
7	0.91	0.97	0.94	0.08	Isothermality
6	0.91	0.97	0.55	0.60	Precipitation of warmest quarter
5	0.94	0.97	0.60	0.53	Precipitation of coldest quarter
4	0.93	0.96	0.19	1.32	Temperature annual range
3	0.94	0.95	0.10	1.63	Geology
2	**0.93**	**0.95**	**0.79**	**0.26**	**Biome**
1	0.90	0.94	0.002	3.06	Mean temperature of coldest quarter (i.e., with only land use/land cover)

Appendix 1af. *Rhinolophus denti*.

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
8	0.84	0.93			
7	0.84	0.93	1.00	0.00	Precipitation of coldest quarter
6	0.84	0.93	0.79	0.27	Mean temperature of wettest quarter
5	0.82	0.92	0.71	0.38	Mean temperature of driest quarter
4	0.84	0.92	0.79	0.26	Biome
3	0.84	0.92	1.00	0.00	Precipitation of warmest quarter
2	**0.87**	**0.91**	**0.36**	**0.91**	**Temperature annual range**
1	0.86	0.87	0.02	2.40	Geology (i.e., with only land use/land cover)

Appendix 1ag. *Tadarida aegyptiaca***.**

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
12	0.50	0.70			
11	0.50	0.70	0.94	-0.08	Temperature annual range
10	0.50	0.70	0.91	0.11	Annual mean temperature
9	0.51	0.66	0.0002	3.67	Geology
8	0.51	0.66	0.71	0.38	Precipitation of driest month
7	0.51	0.65	0.65	0.45	Mean temperature of warmest quarter
6	0.52	0.65	0.68	0.42	Maximum temperature of warmest month
5	0.52	0.64	0.47	0.72	Minimum temperature of coldest month
4	0.53	0.64	0.60	0.53	Precipitation of warmest quarter
3	0.54	0.62	0.04	2.08	Biome
2	**0.52**	**0.61**	**0.19**	**1.32**	**Elevation**
1	0.52	0.60	0.34	0.94	Precipitation of driest quarter (i.e., with only land use/land cover)

Appendix 1ah. *Taphozous mauritianus.*

Number of variables per model	Average test AUC	Average training AUC	p-value	Z score	Predictor variable removed
8	0.70	0.91			
7	0.70	0.91	0.97	0.04	Isothermality
6	0.71	0.91	0.73	0.34	Precipitation seasonality
5	0.71	0.91	0.91	0.11	Biome
4	0.73	0.90	0.76	0.30	Mean temperature of coldest quarter
3	**0.74**	**0.90**	**0.73**	**0.34**	**Precipitation of warmest quarter**
2	0.69	0.89	0.05	1.93	Temperature annual range
1	0.59	0.85	0.0002	3.67	Land use/Land cover (i.e., with only geology)

Appendix 1ai. *Myotis welwitschi***.**

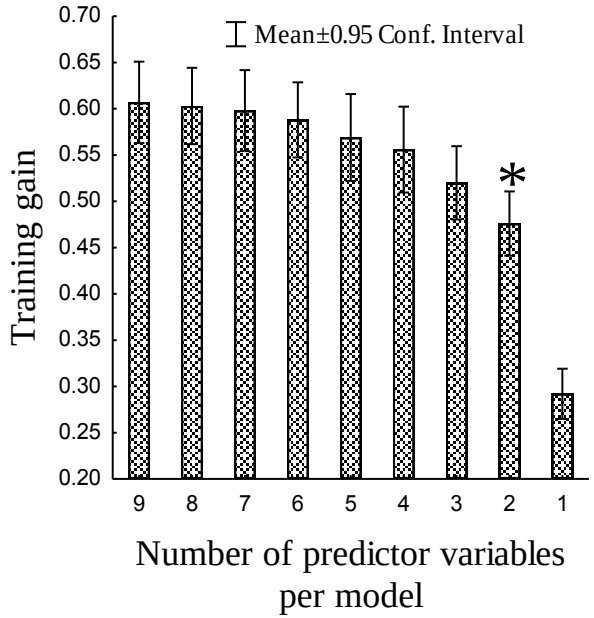
Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
9	0.84	0.93			
8	0.84	0.93	1.00	0.00	Annual mean temperature
7	0.84	0.93	1.00	0.00	Mean temperature of coldest quarter
6	0.84	0.93	1.00	0.00	Temperature seasonality
5	0.84	0.93	0.91	0.11	Isothermality
4	0.83	0.93	0.73	0.34	Precipitation seasonality
3	0.83	0.93	0.24	-1.17	Biome
2	**0.84**	**0.90**	**0.001**	**3.29**	**Geology**
1	0.81	0.83	0.0004	3.51	Land use/Land cover (i.e., with only precipitation of warmest quarter)

Appendix 1aj. *Rhinolophus capensis.*

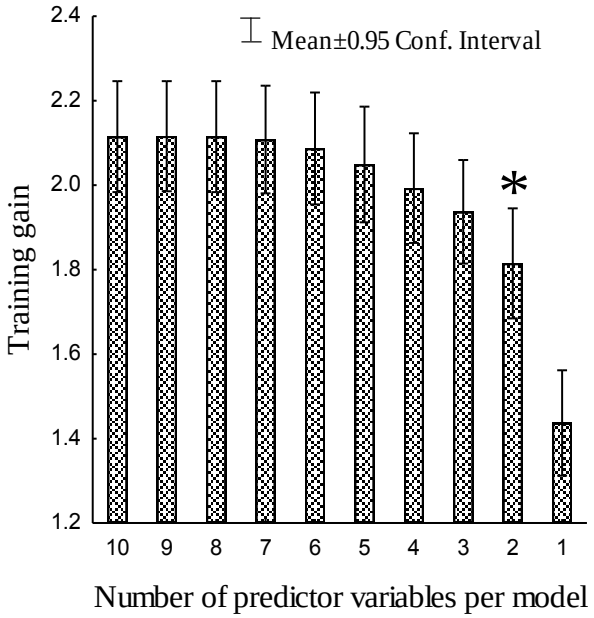
Number of variables per model	Average Test AUC	Average Training AUC	P-value	Z score	Predictor variable removed
11	0.91				
10	0.92	0.98	0.71	0.38	Isothermality
9	0.92	0.98	0.73	0.34	Precipitation seasonality
8	0.92	0.97	0.89	0.15	Mean temperature of driest quarter
7	0.92	0.97	0.83	0.41	Diurnal temperature range
6	0.92	0.97	0.82	0.23	Mean temperature of wettest quarter
5	0.92	0.97	0.21	1.24	Mean temperature of coldest quarter
4	0.91	0.97	0.09	1.70	Elevation
3	**0.92**	**0.96**	**0.10**	**1.63**	**Land use/Land cover**
2	0.93	0.95	0.0004	3.52	Geology
1	0.90	0.92	0.0002	3.74	Precipitation of coldest quarter (i.e., with only biome)

Appendix 2

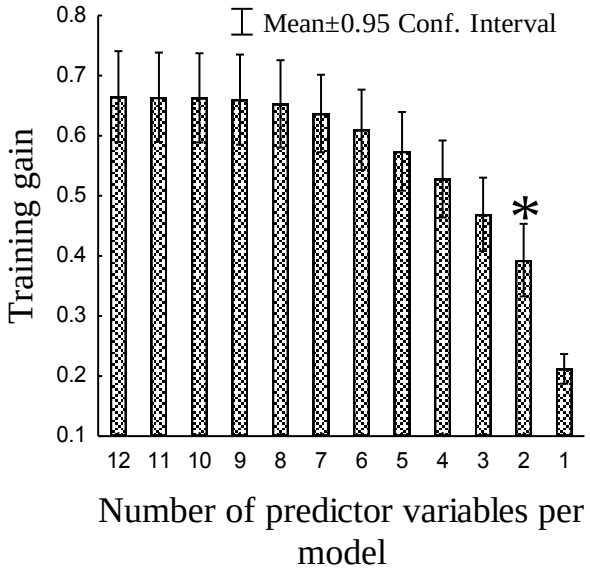
The training gain averaged across the 10 random partitions of the presence records for different South African bat species using MaxEnt modelling. The model with an asterisk (*) in each graph is the best model selected, that is, the best model is the one for which the average training gain is significantly different from the smaller models but not significantly different from the larger ones.



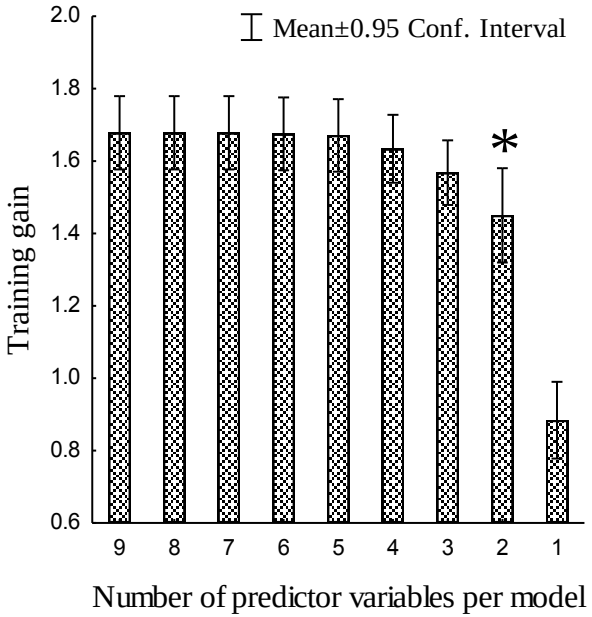
Appendix 2a. *Rhinolophus clivosus*.



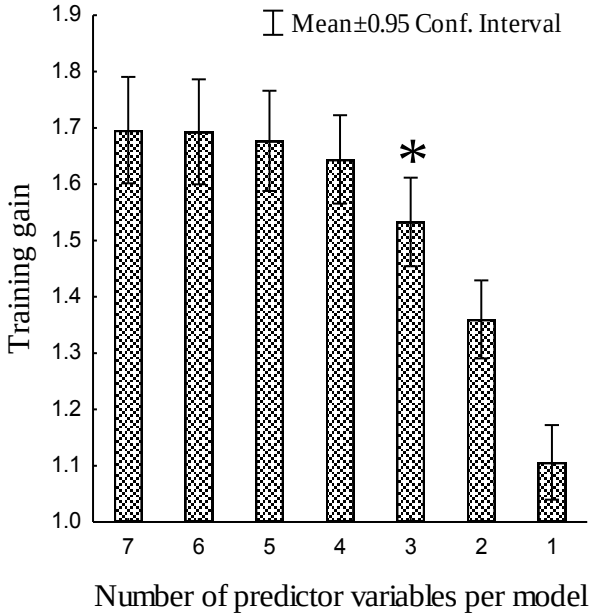
Appendix 2b. *Pipistrellus hesperidus*.



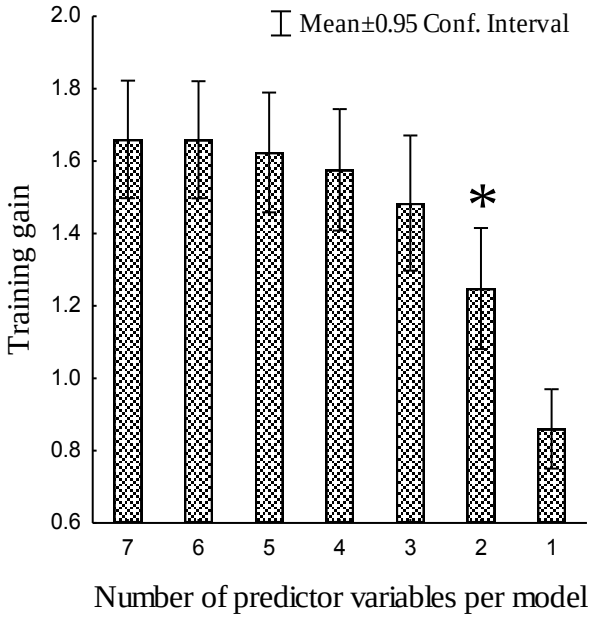
Appendix 2c. *Eidolon helvum.*



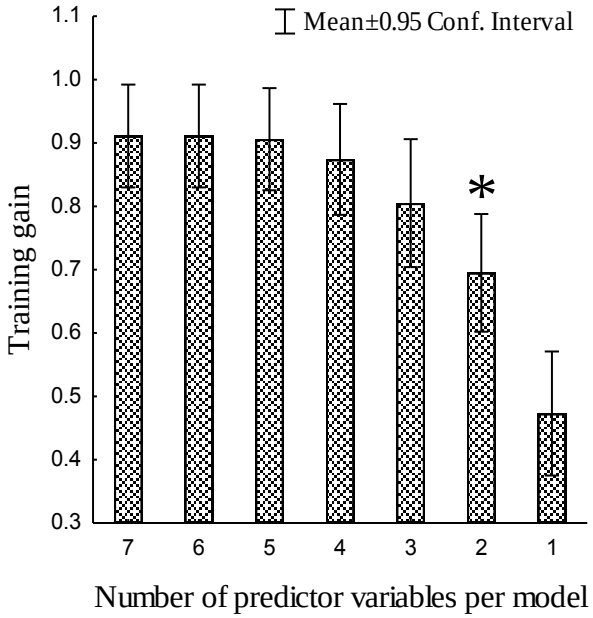
Appendix 2d. *Mops midas*.



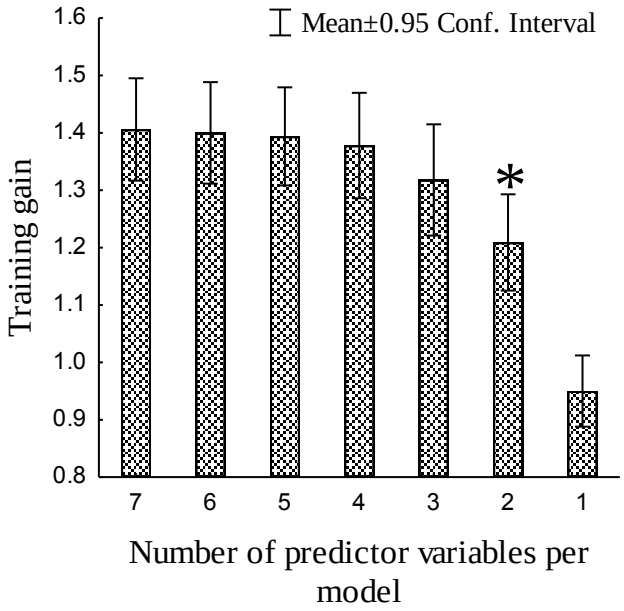
Appendix 2e. *Pipistrellus rusticus*.



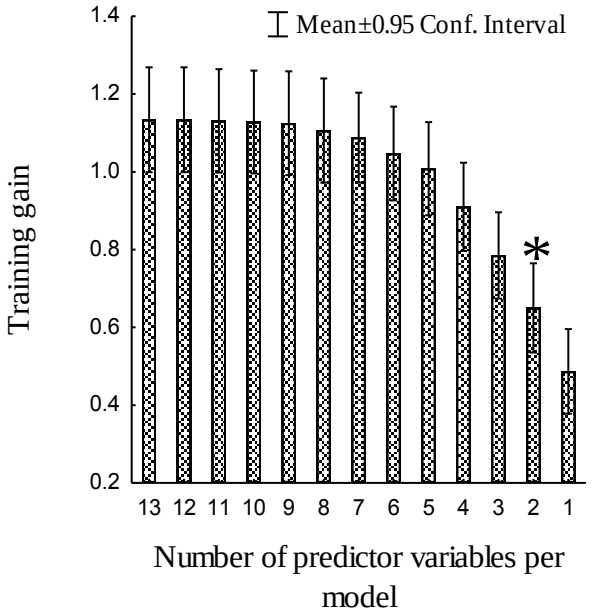
Appendix 2f. *Rhinolophus hildebrandtii***.**



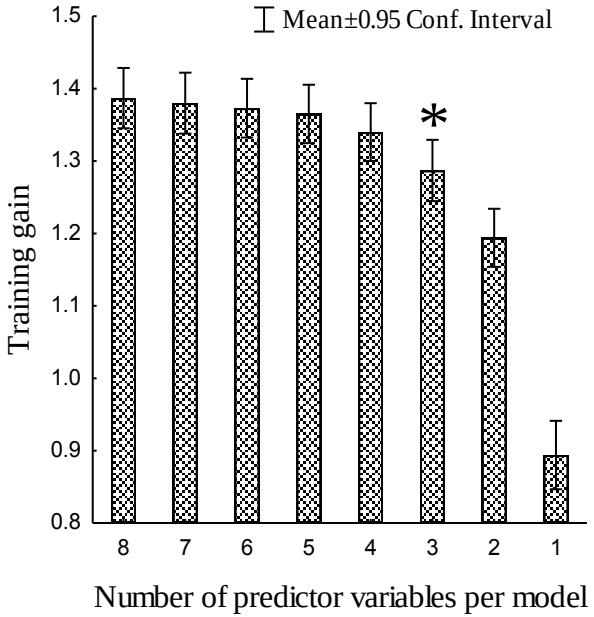
Appendix 2g. *Rhinolophus blasii*.



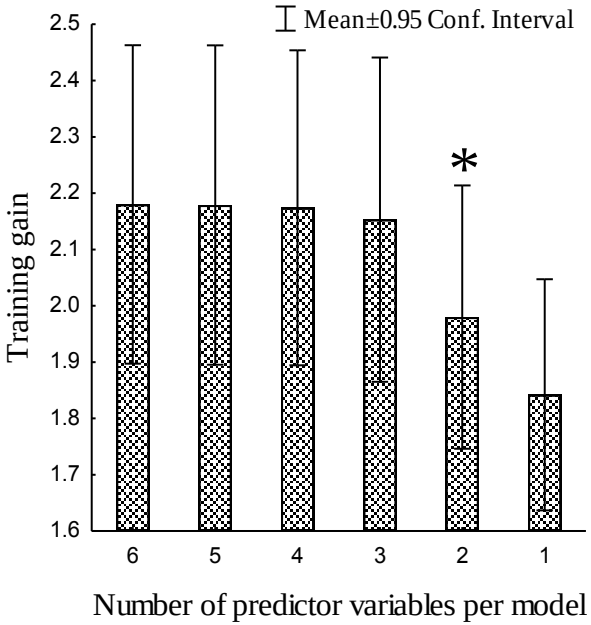
Appendix 2h. *Rhinolophus simulator***.**



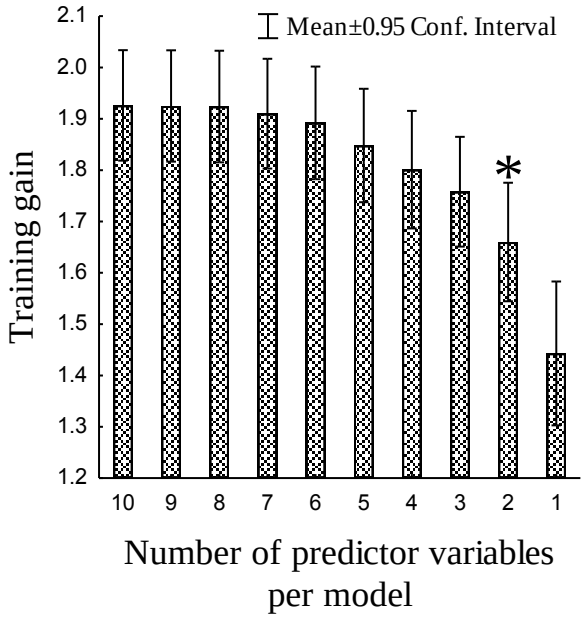
Appendix 2i. *Neoromicia melckorum.*



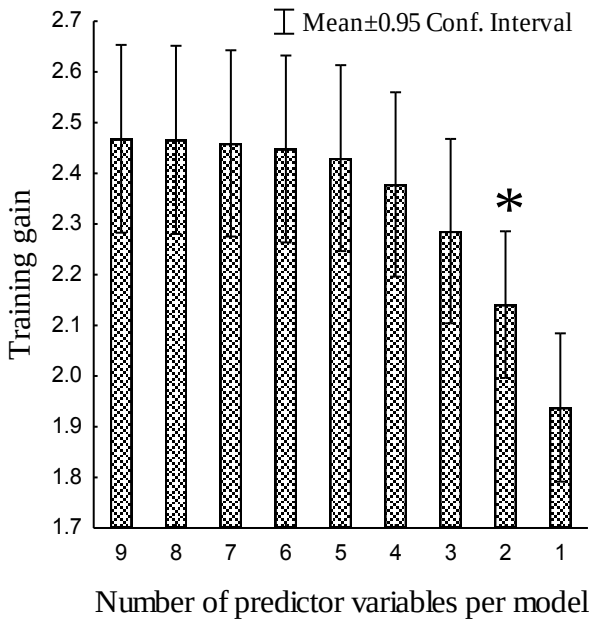
Appendix 2j. *Scotophilus dinganii*.



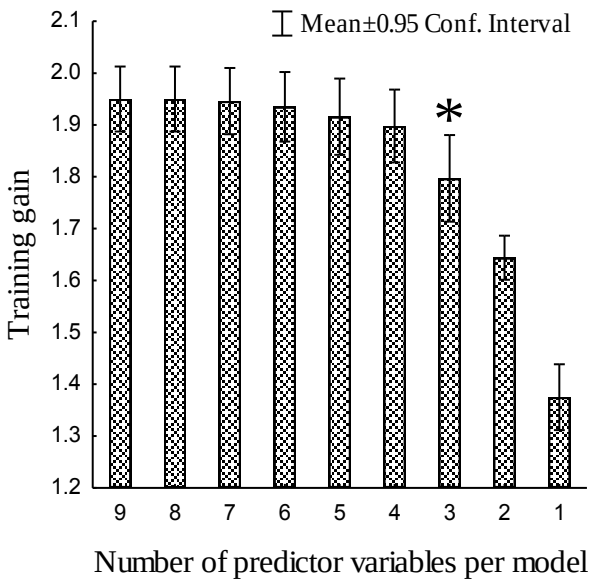
Appendix 2k. *Scotophilus viridis*.



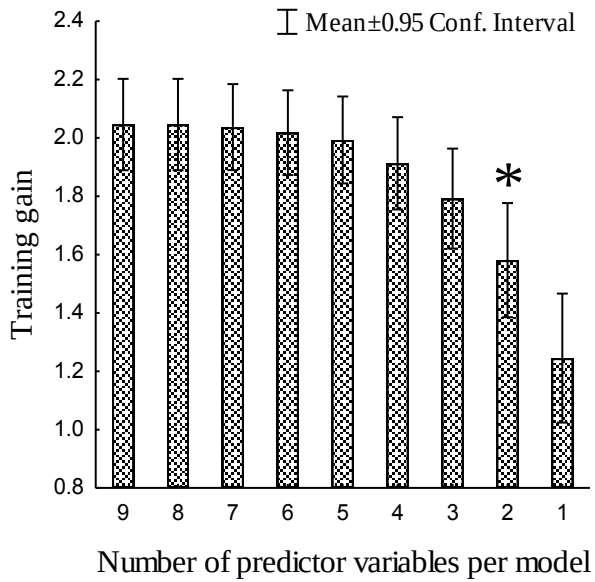
Appendix 2l. *Chaerephon pumilus*.



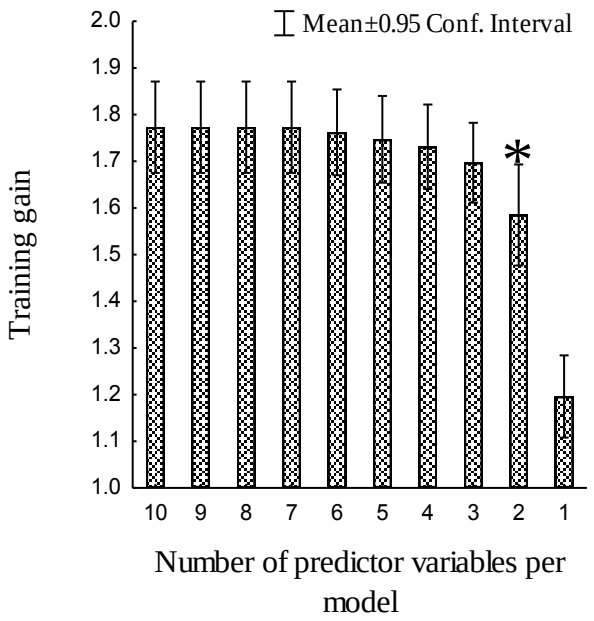
Appendix 2m. *Mops condylurus*.



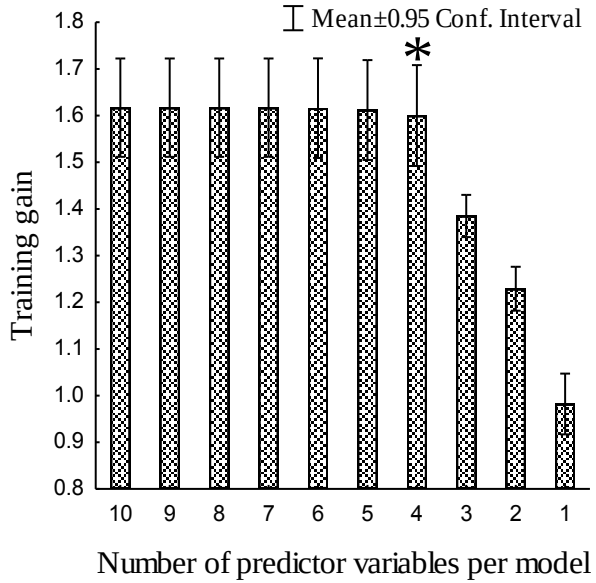
Appendix 2n. *Hipposideros caffer*.



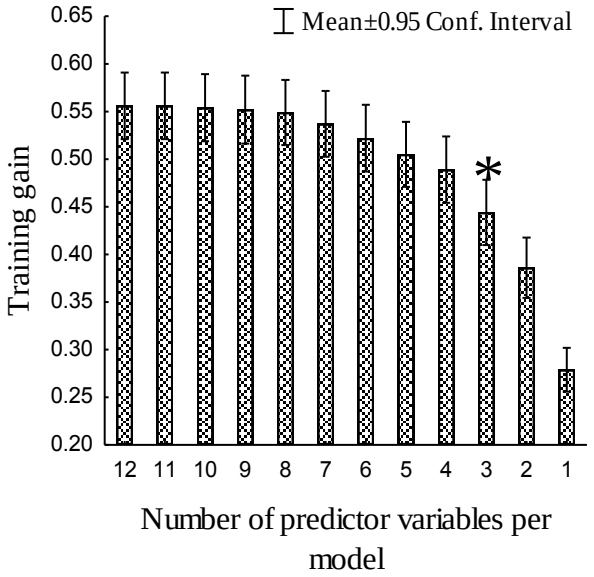
Appendix 2o. *Epomophorus crypturus*.



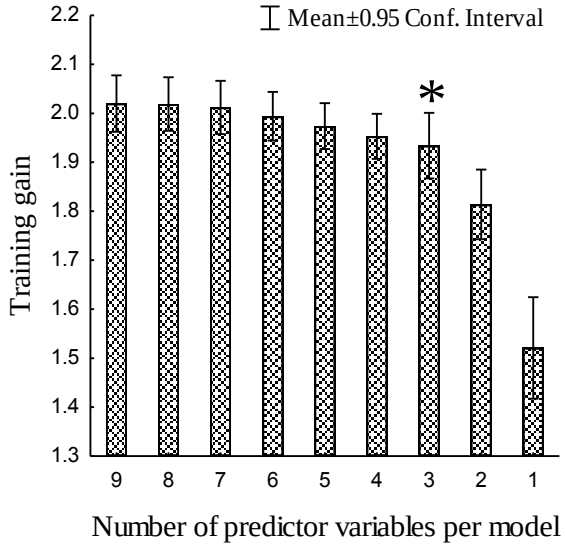
Appendix 2p. *Rhinolophus swinnyi*.



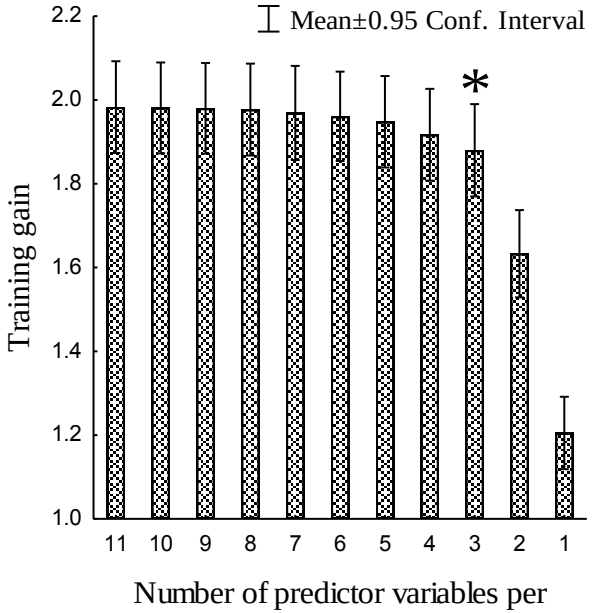
Appendix 2q. *Kerivoula lanosa***.**



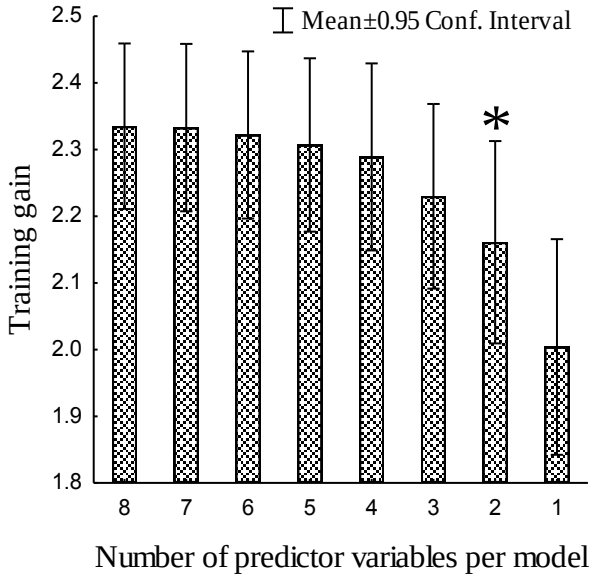
Appendix 2r. *Nycteris thebaica.*



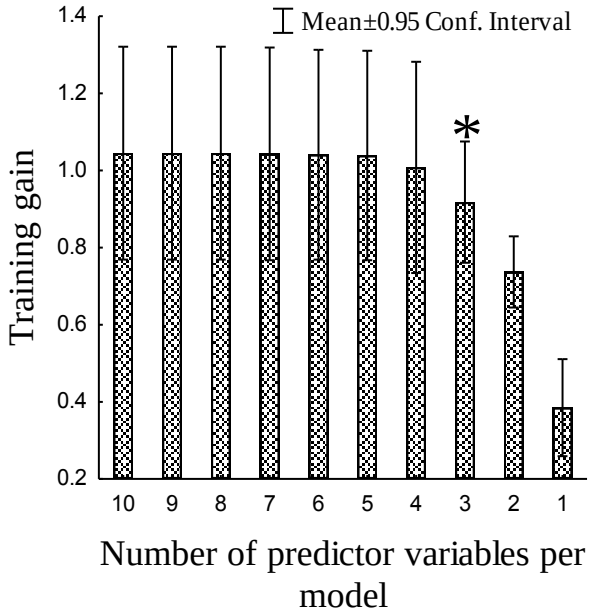
Appendix 2s. *Neoromicia nana.*



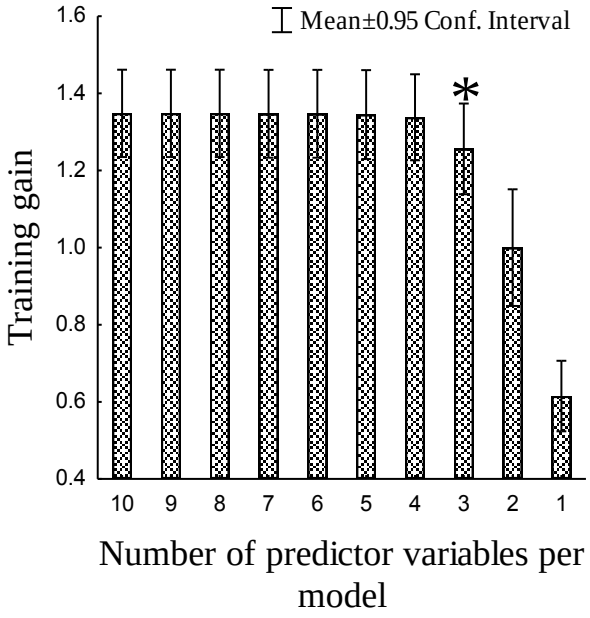
Appendix 2t. *Miniopterus fraterculus*.



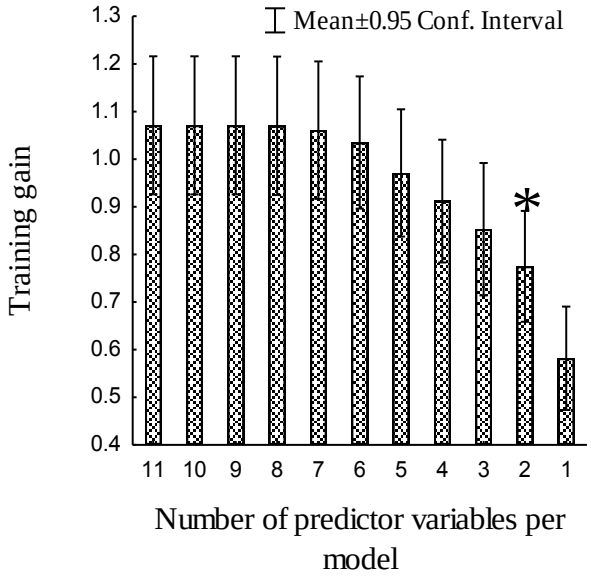
Appendix 2u. *Nycticeinops schlieffeni*.



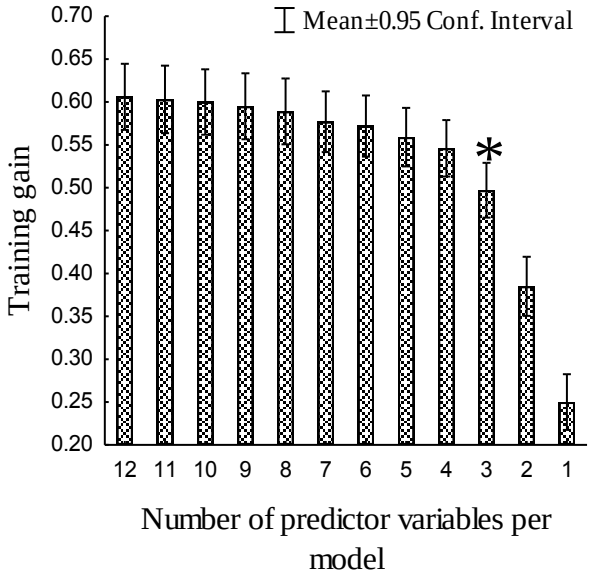
Appendix 2v. *Cistugo lesueuri*.



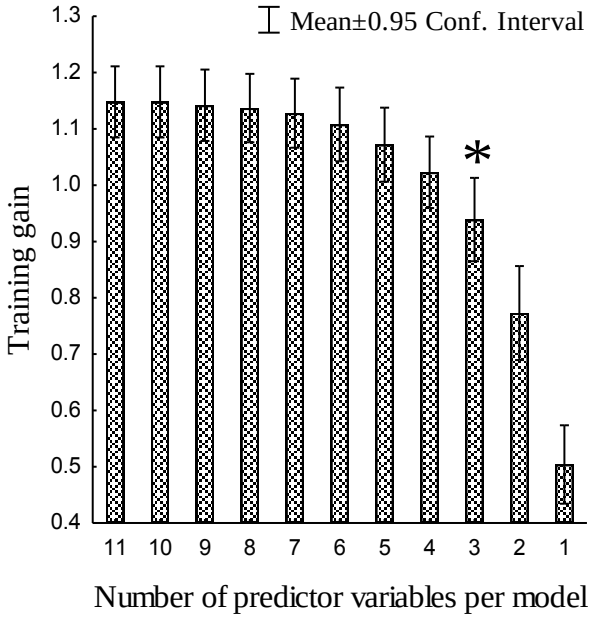
Appendix 2w. *Cloeotis percivali*.



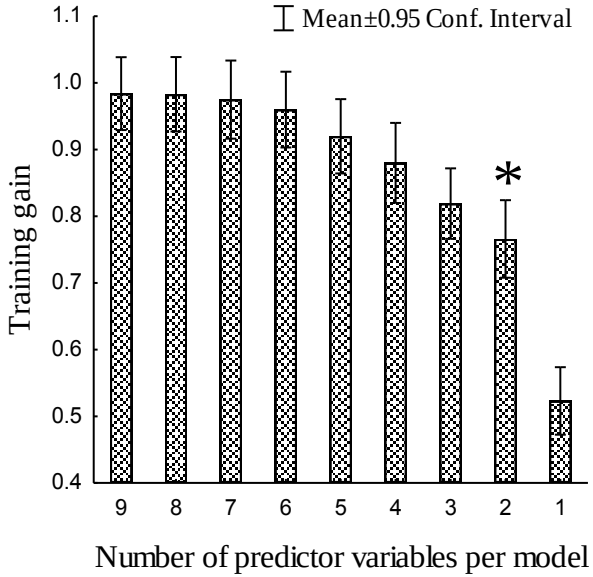
Appendix 2x. *Eptesicus hottentotus*.



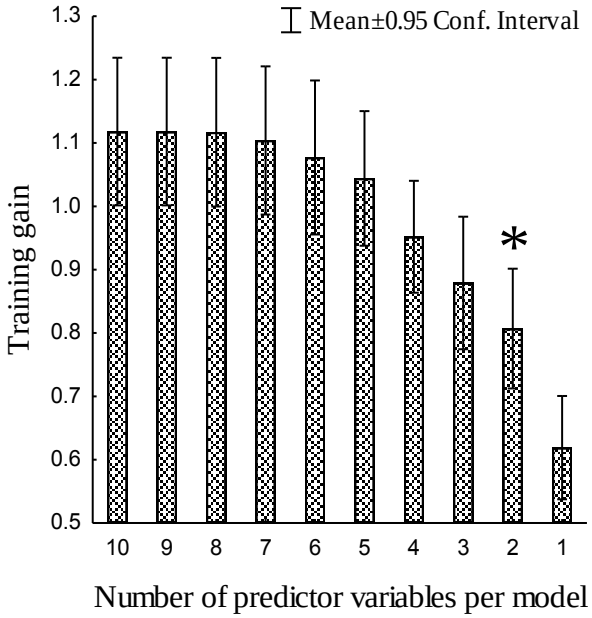
Appendix 2y. *Miniopterus natalensis*.



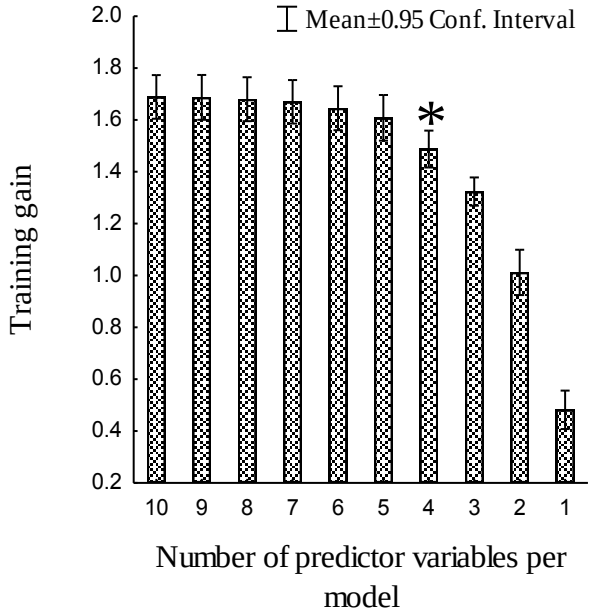
Appendix 2z. *Myotis tricolor***.**



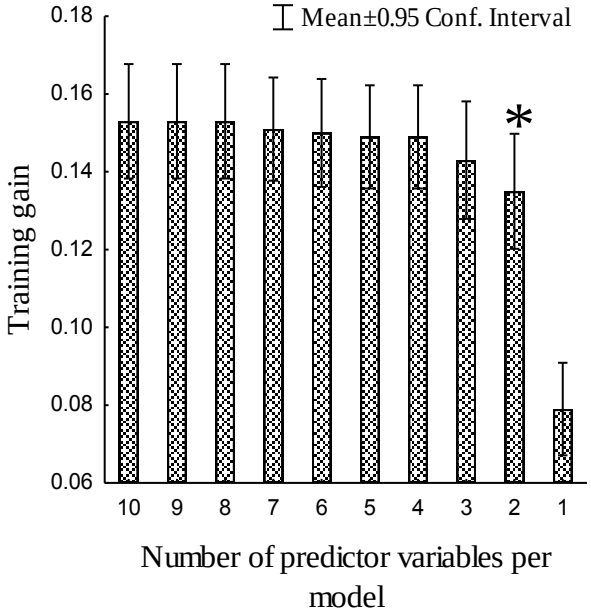
Appendix 2aa. *Rhinolophus darlingi*.



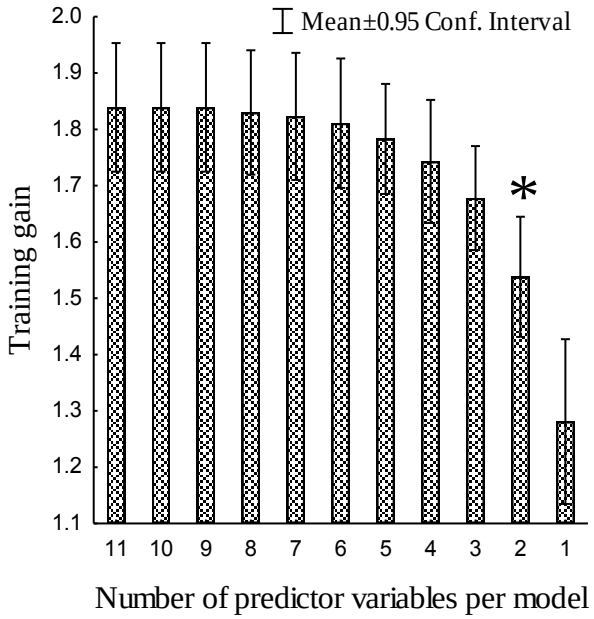
Appendix 2ab. *Sauromys petrophilus***.**



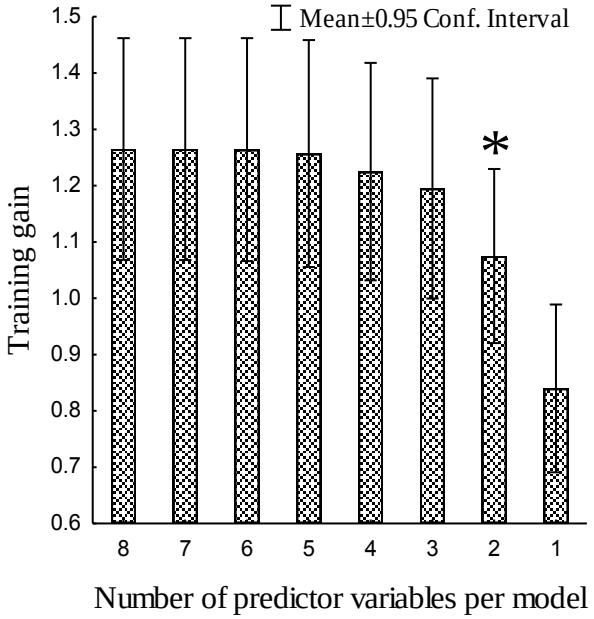
Appendix 2ac. *Rousettus aegyptiacus***.**



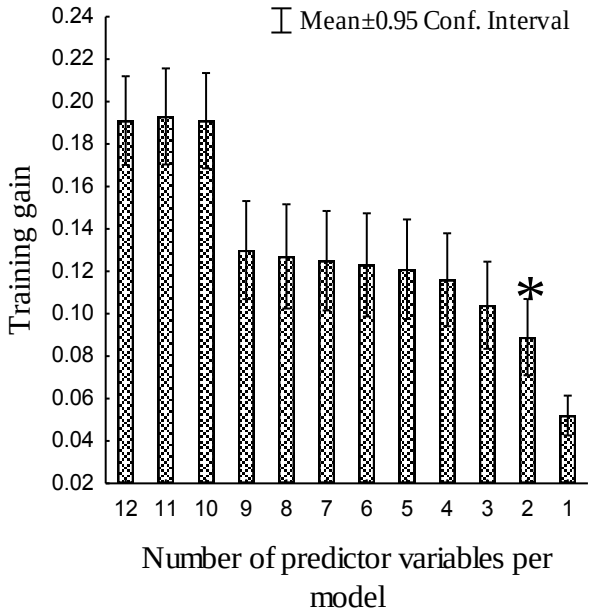
Appendix 2ad. *Neoromicia capensis*.



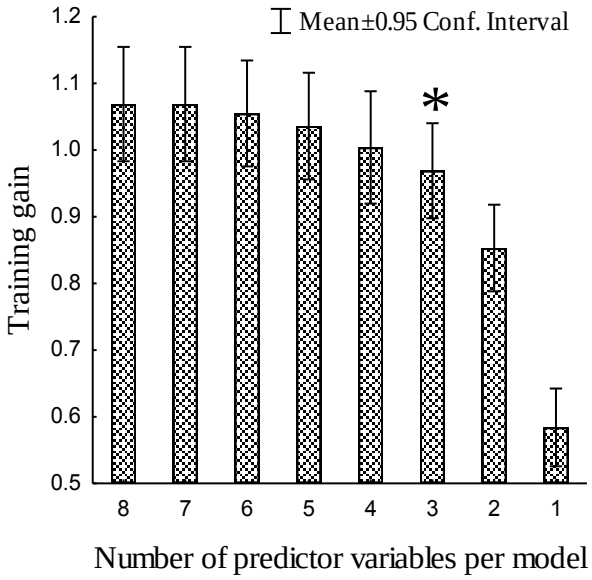
Appendix 2ae. *Neoromicia zuluensis***.**



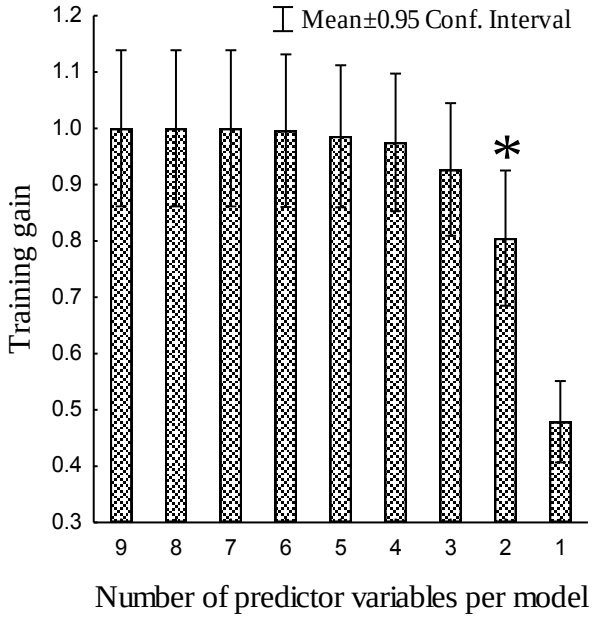
Appendix 2af. *Rhinolophus denti***.**



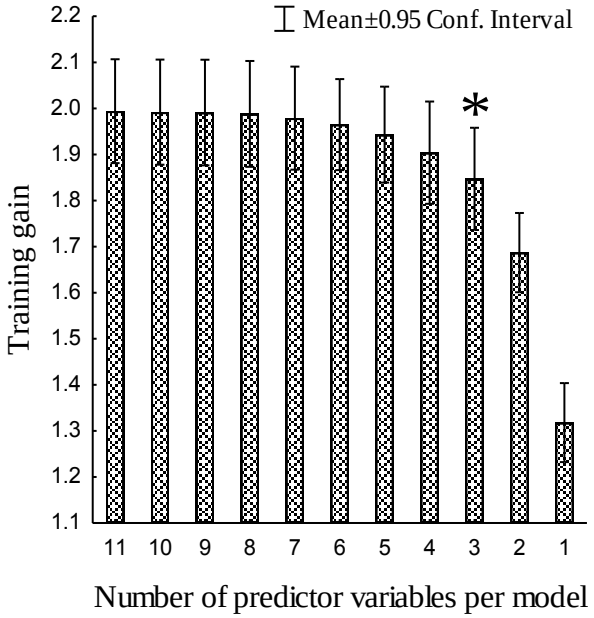
Appendix 2ag. *Tadarida aegyptiaca*.



Appendix 2ah. *Taphozous mauritianus***.**



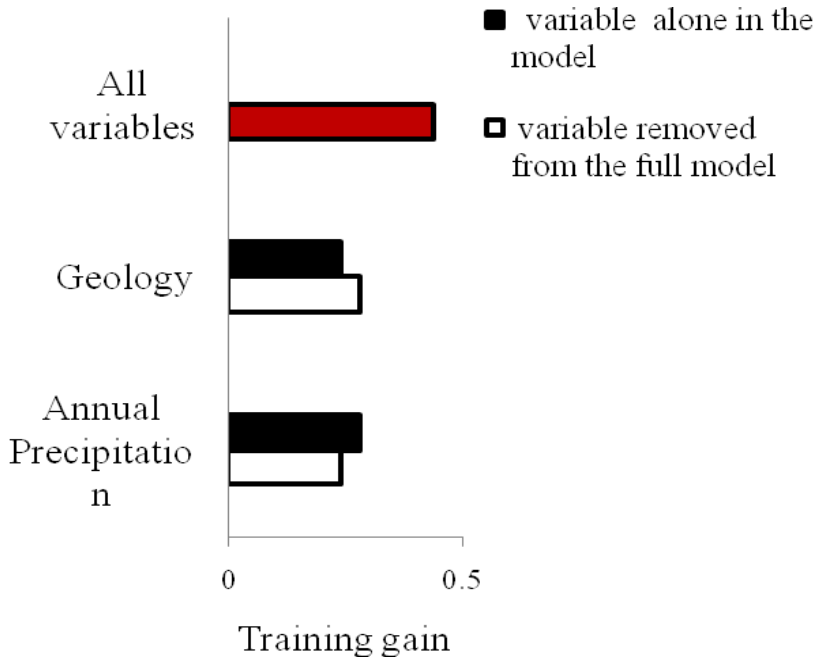
Appendix 2ai. *Myotis welwitschii*.



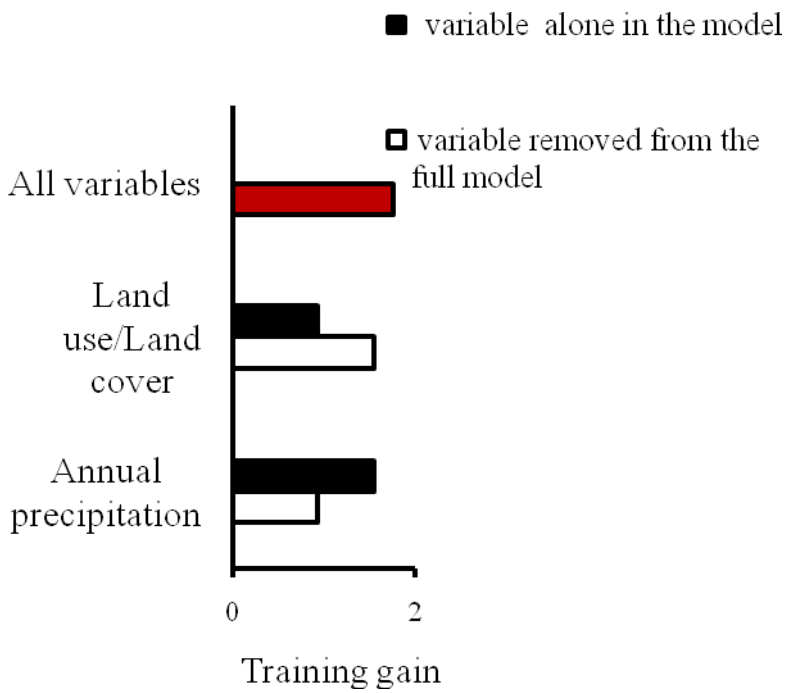
Appendix 2aj. *Rhinolophus capensis***.**

Appendix 3

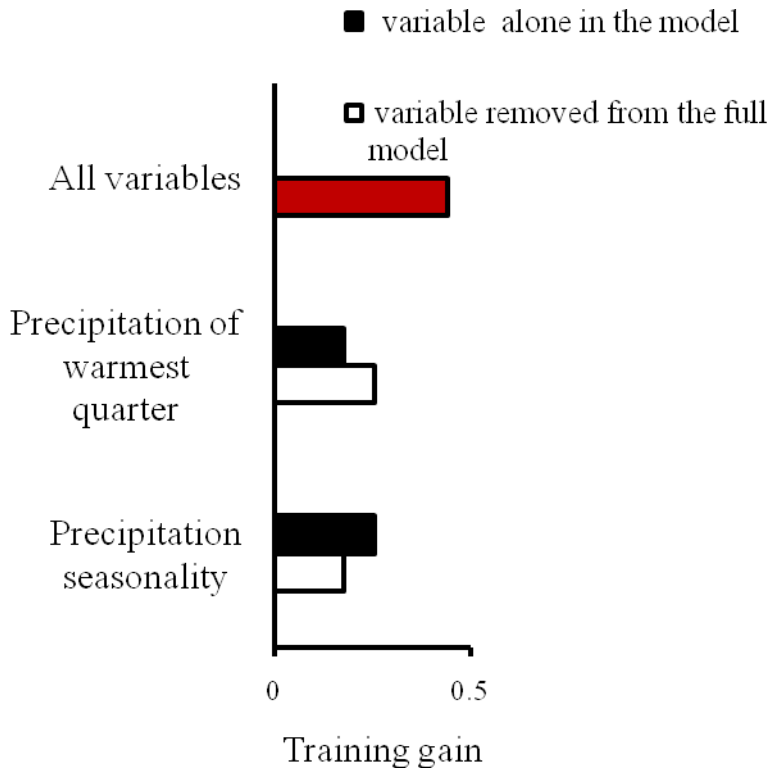
Jackknife test of variable importance in the final model for different South African bat species considered for MaxEnt modelling. The longer the black bar, the better the variable contribution to the model gain when the variable is used alone. The shorter the white bar, the more reduction in model gain when the variable is omitted from the full model.



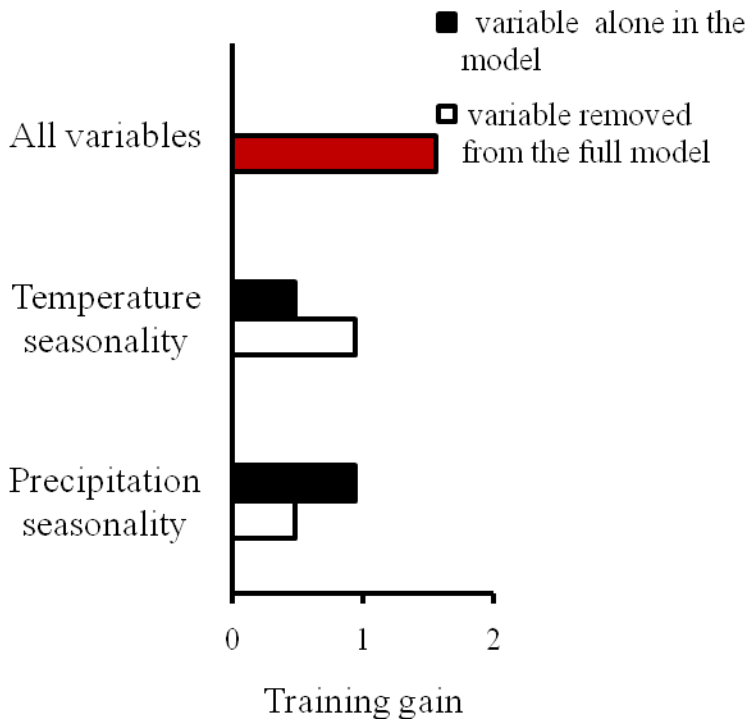
Appendix 3a. *Rhinolophus clivosus*.



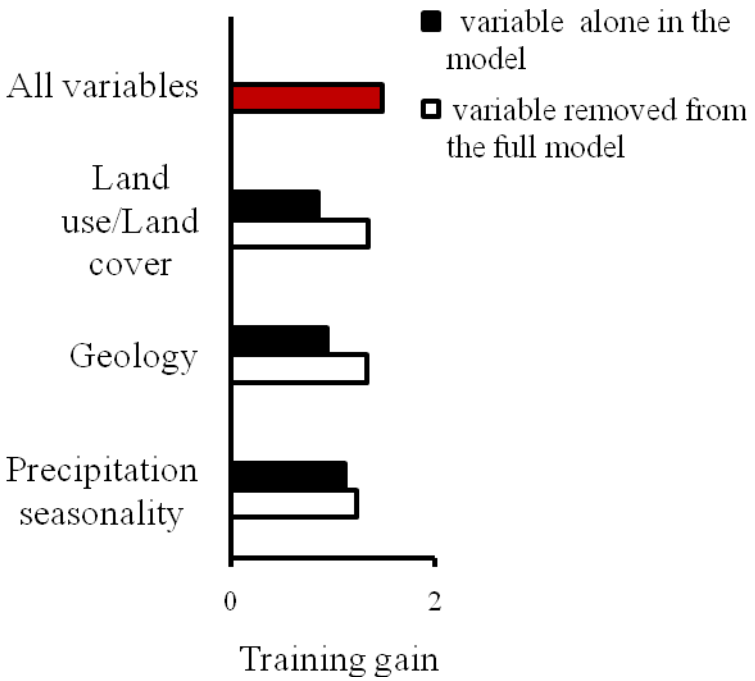
Appendix 3b. *Pipistrellus hesperidus*.



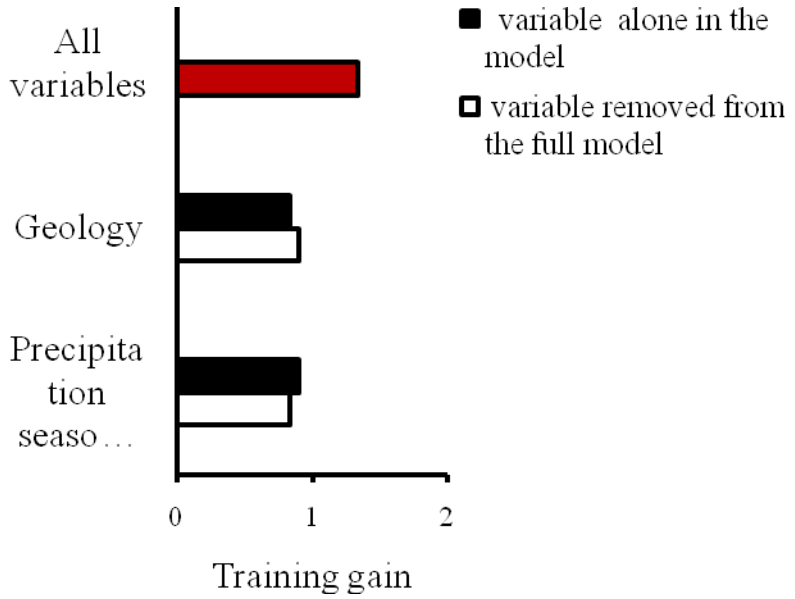
Appendix 3c. *Eidolon helvum*.



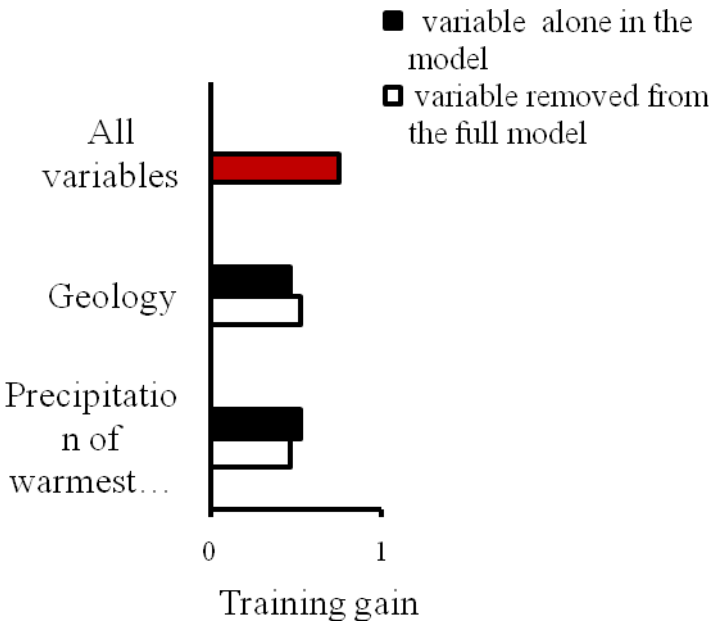
Appendix 3d. *Mops midas*.



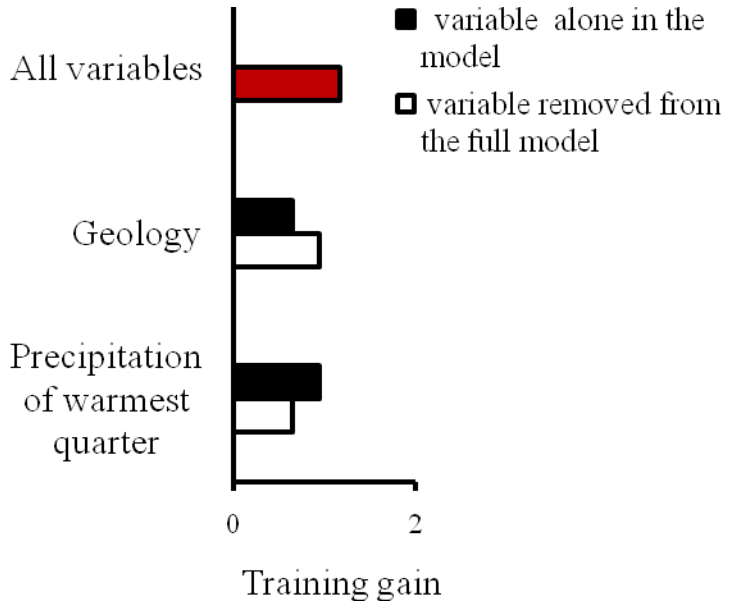
Appendix 3e. *Pipistrellus rusticus*.



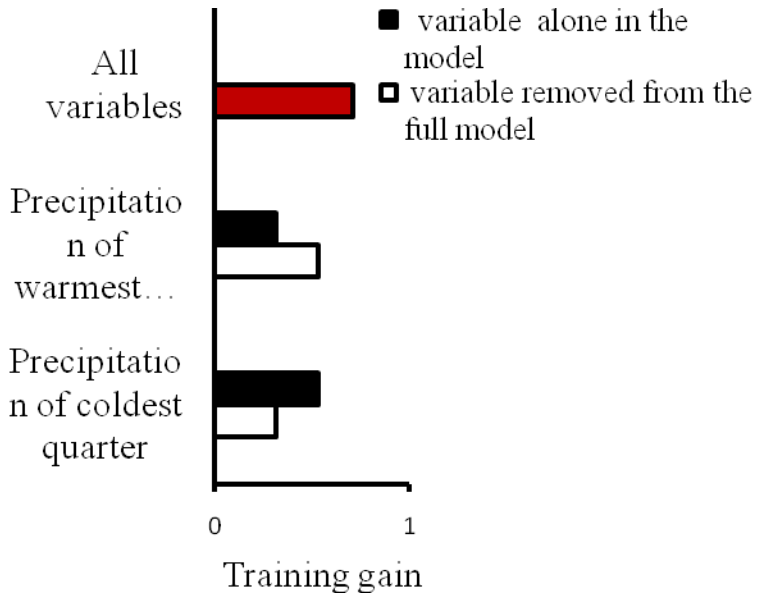
Appendix 3f. *Rhinolophus hildebrandtii*.



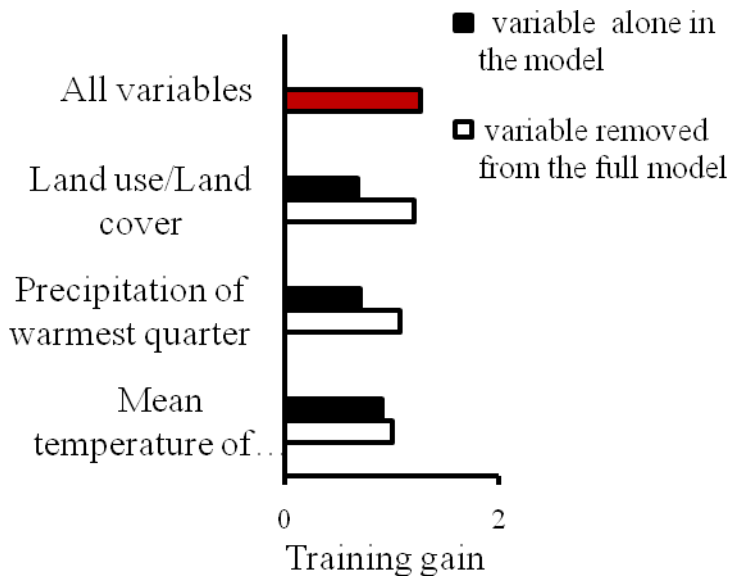
Appendix 3g. *Rhinolophus blasii*.



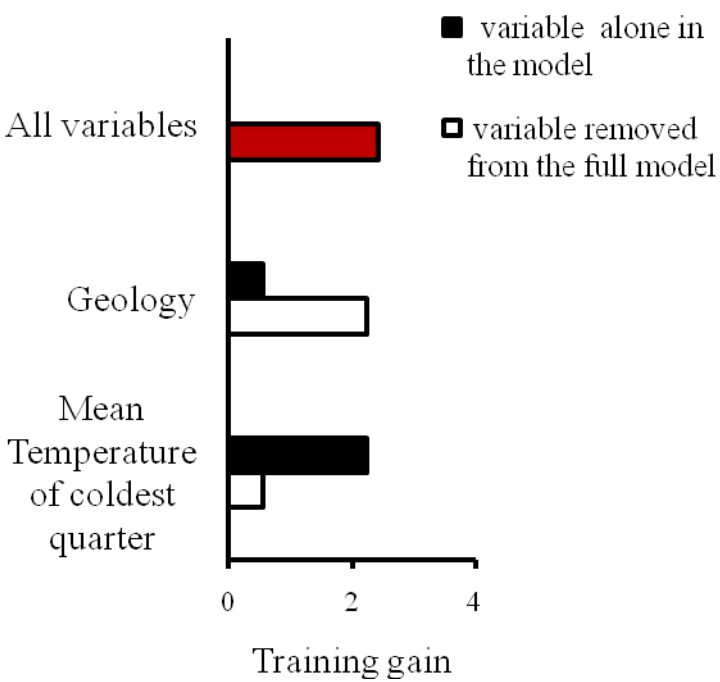
Appendix 3h. *Rhinolophus simulator*.



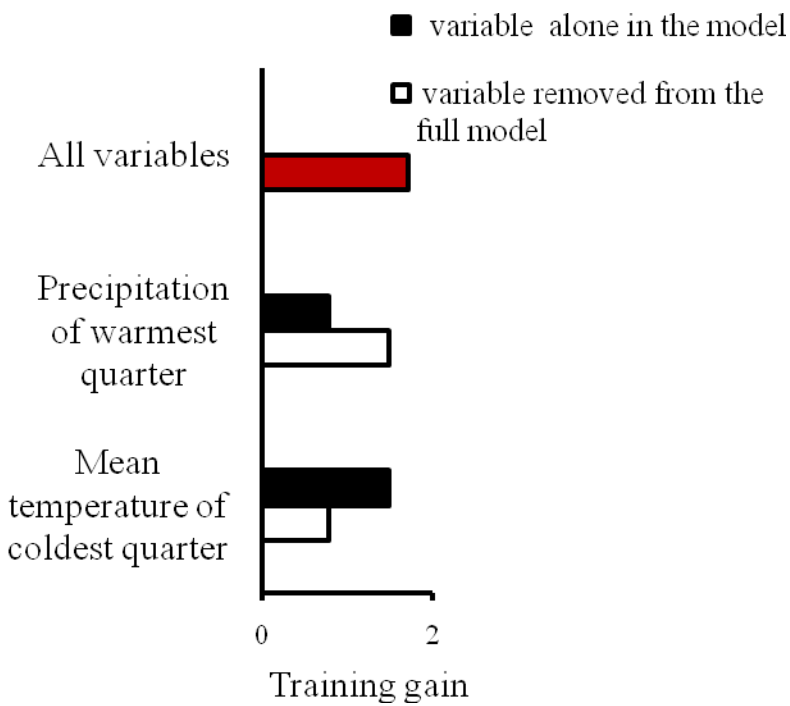
Appendix 3i. *Neoromicia melckorum*.



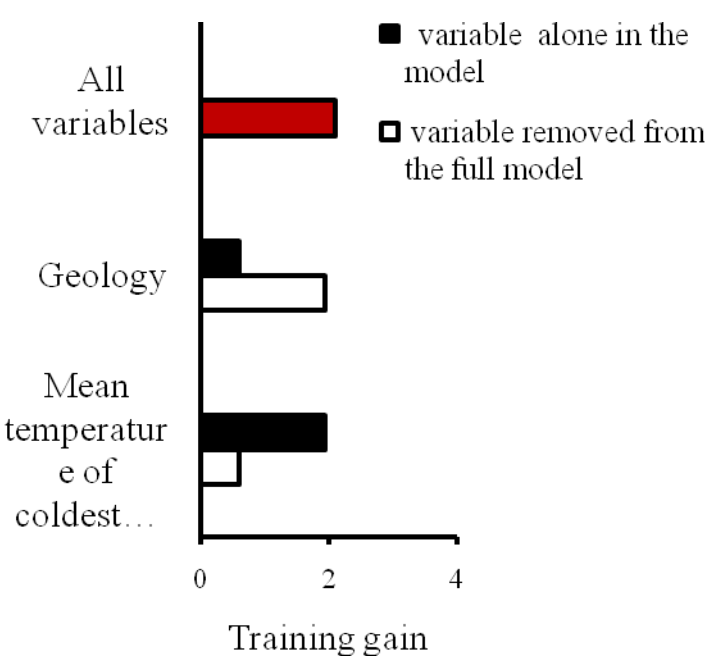
Appendix 3j. *Scotophilus dinganii*.



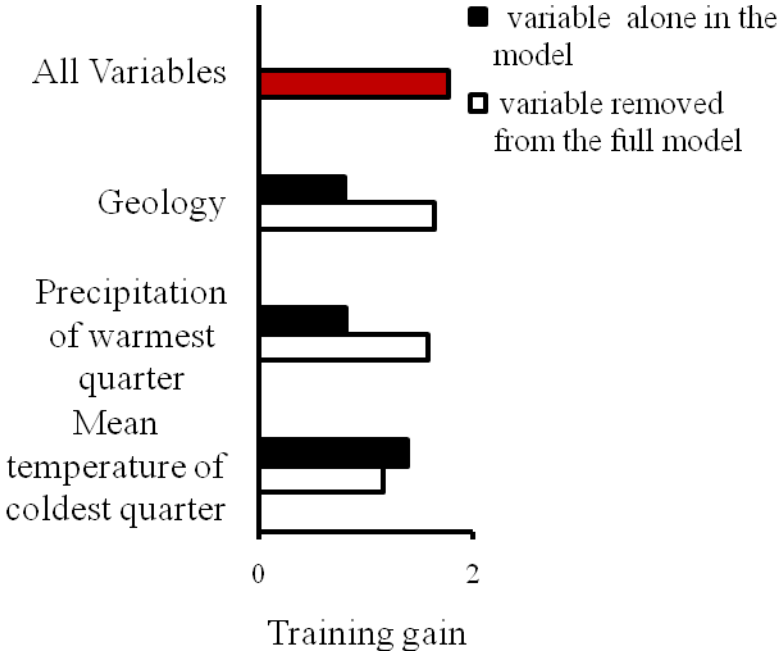
Appendix 3k. *Scotophilus viridis*.



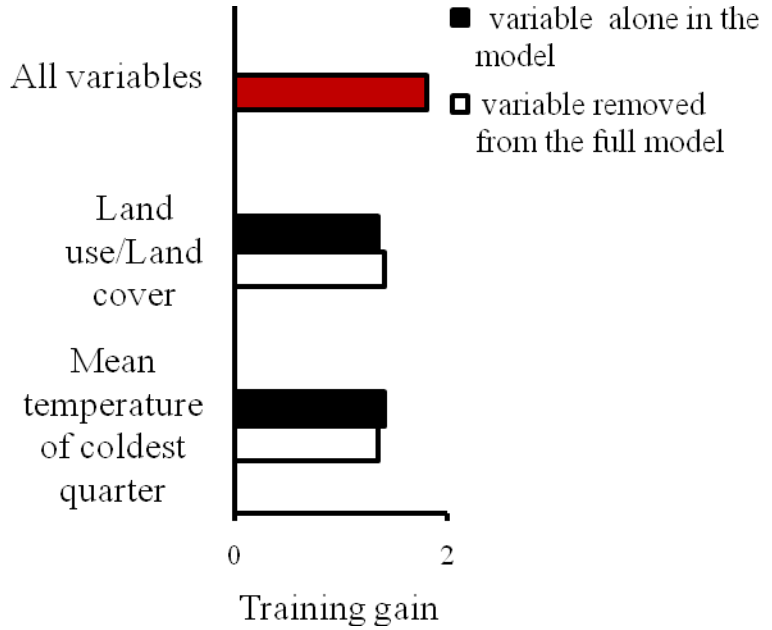
Appendix 3l. *Chaerephon pumilus*.



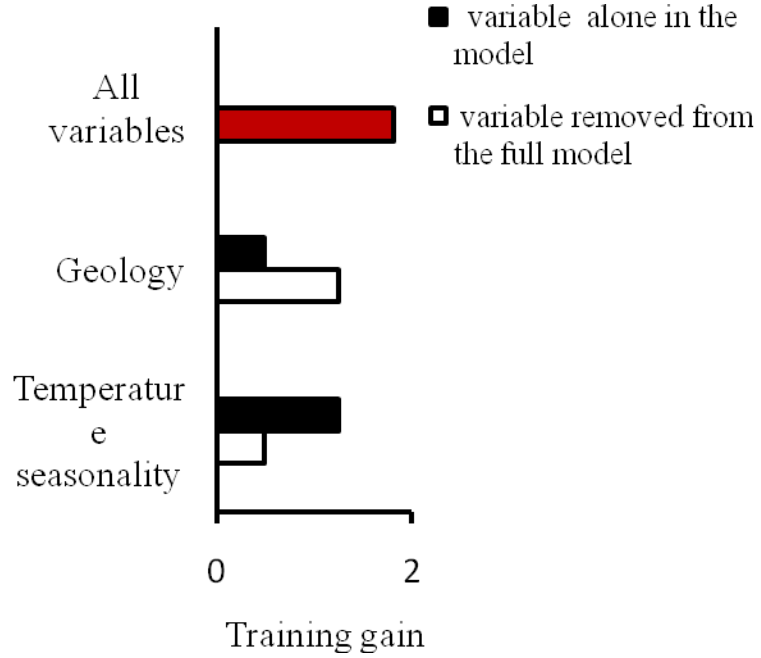
Appendix 3m. *Mops condylurus*.



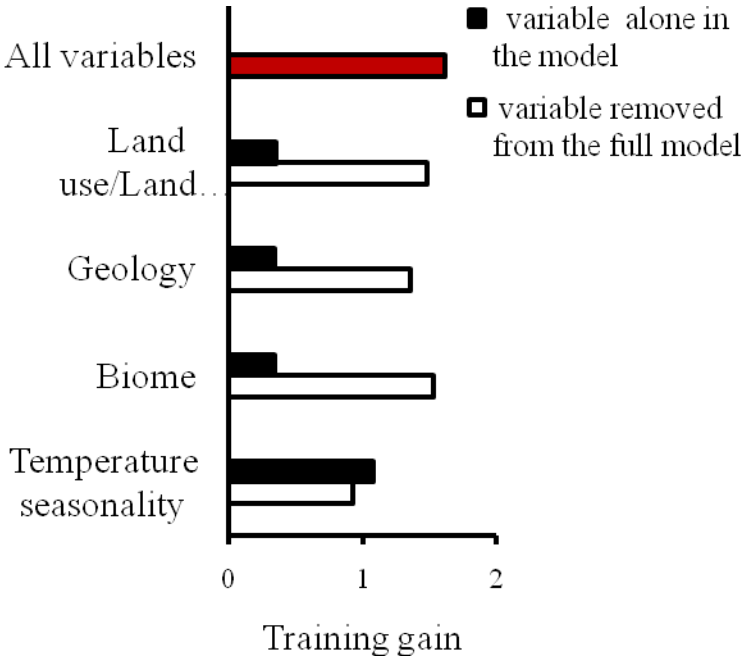
Appendix 3n. *Hipposideros caffer*.



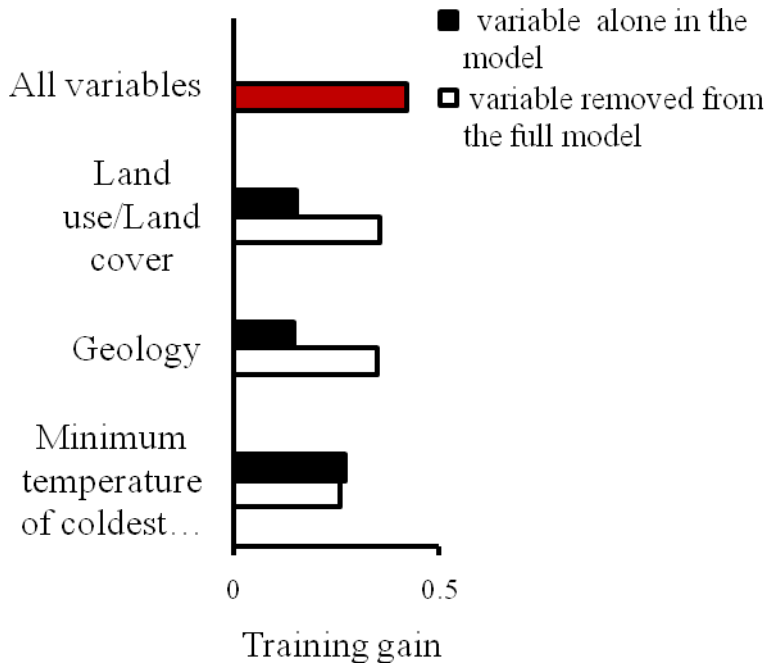
Appendix 3o. *Epomophorus crypturus*.



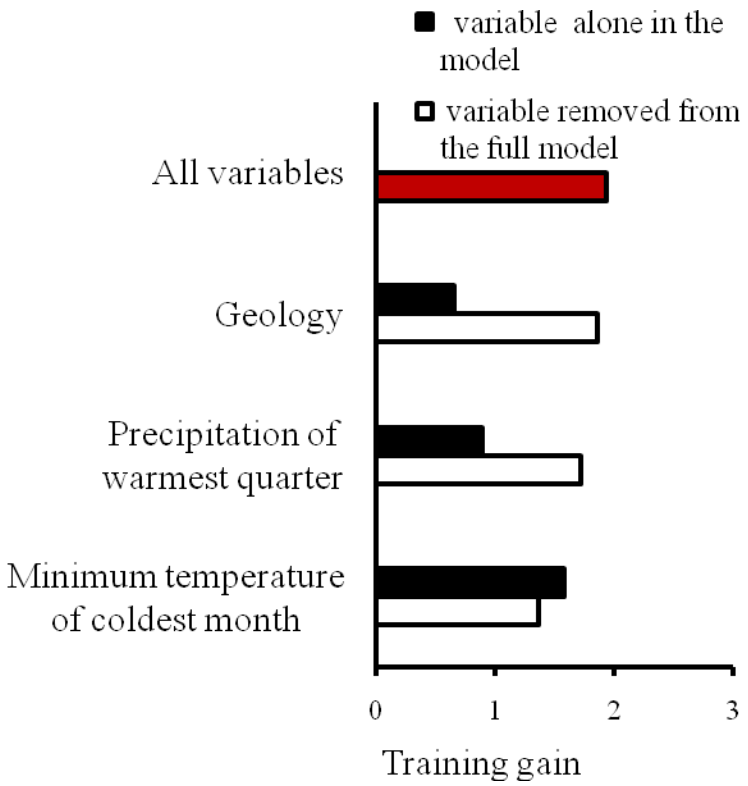
Appendix 3p. *Rhinolophus swinnyi*.



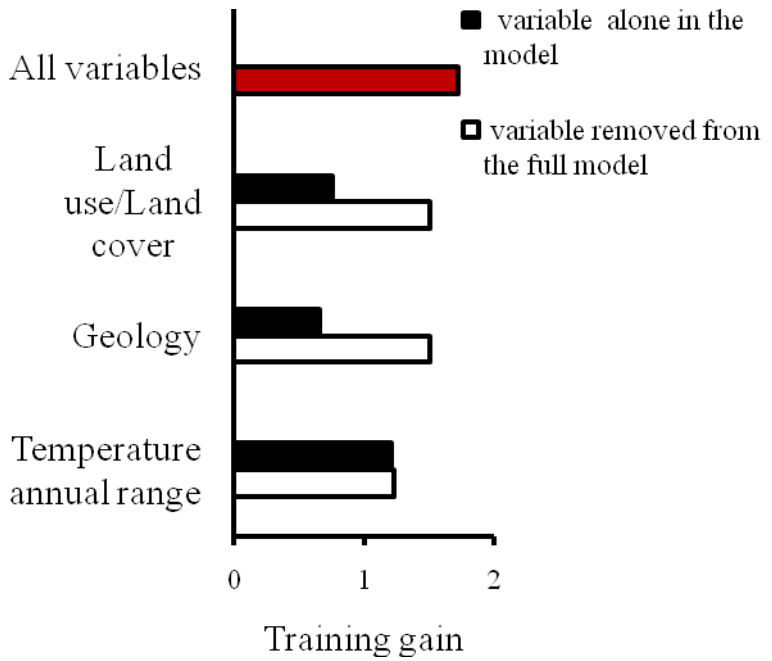
Appendix 3q. *Kerivoula lanosa*.



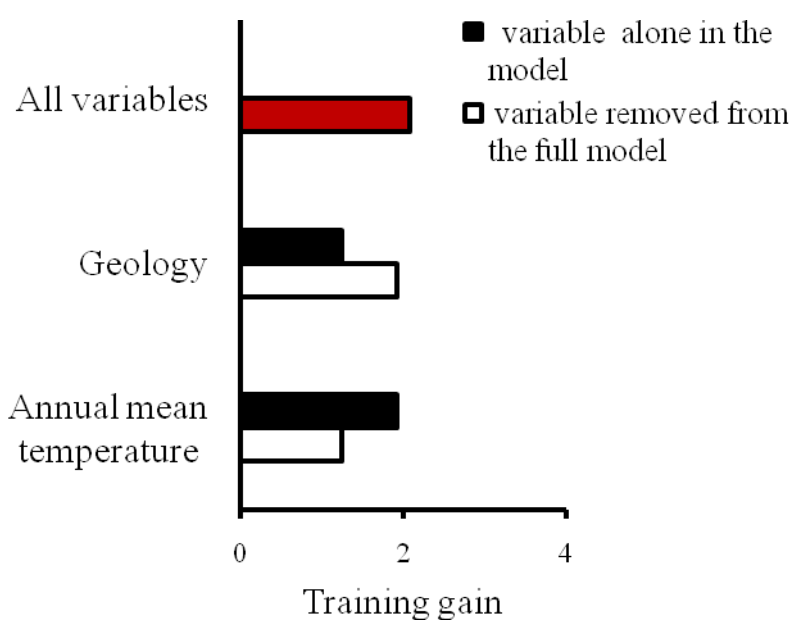
Appendix 3r. *Nycteris thebaica*.



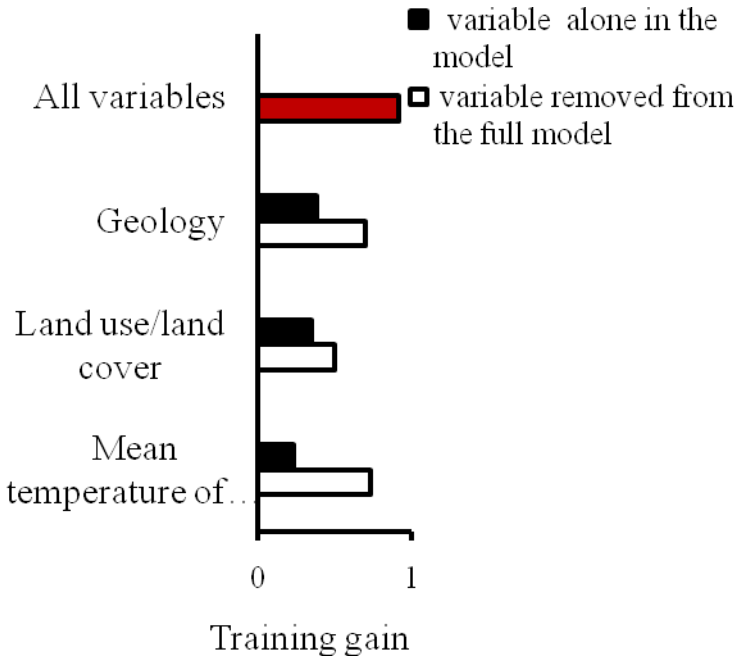
Appendix 3s. *Neoromicia nana.*



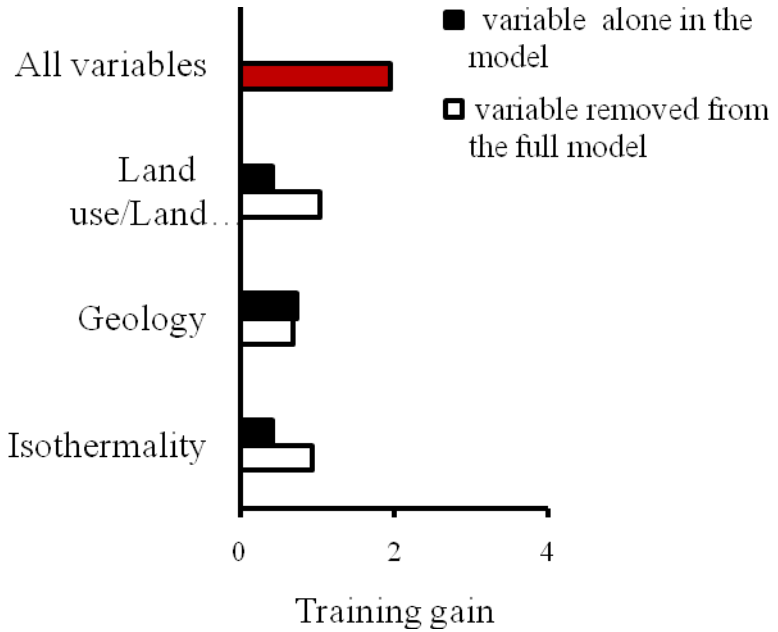
Appendix 3t. *Miniopterus fraterculus*.



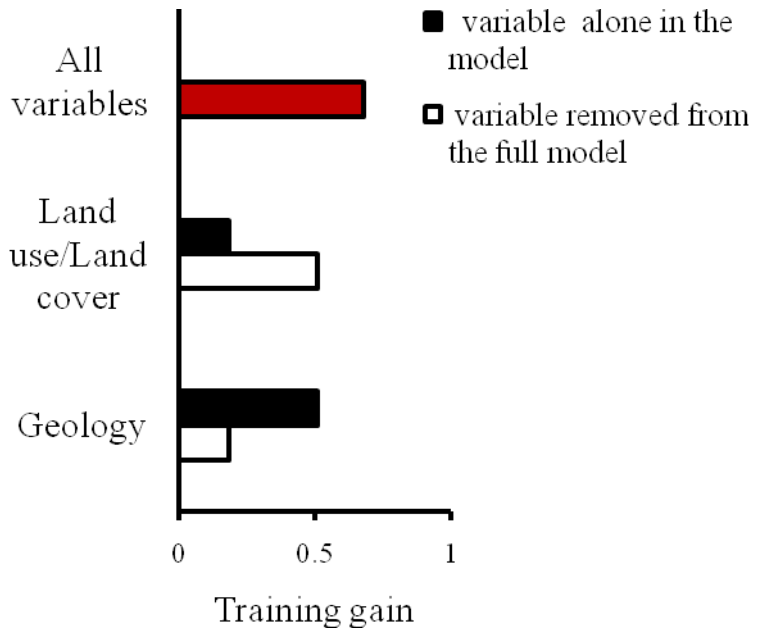
Appendix 3u. *Nycticeinops schlieffeni*.



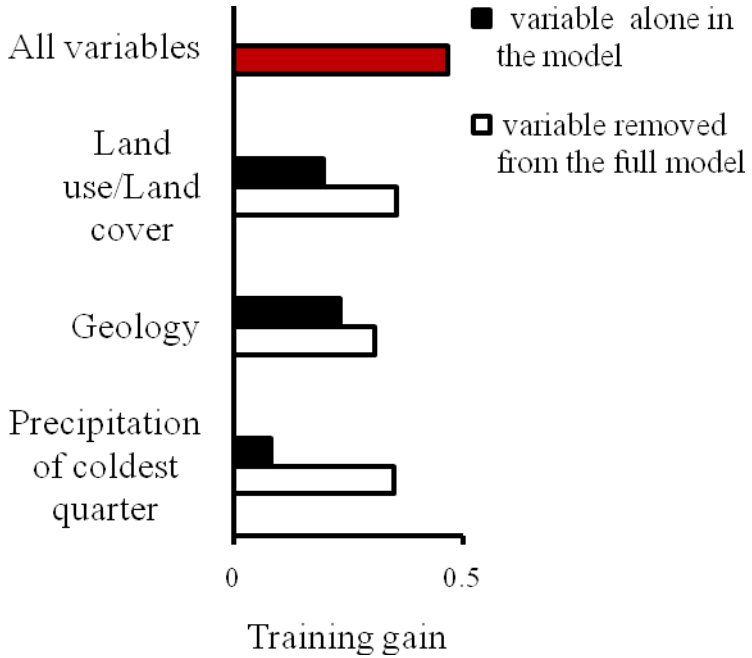
Appendix 3v. *Cistugo lesueuri*.



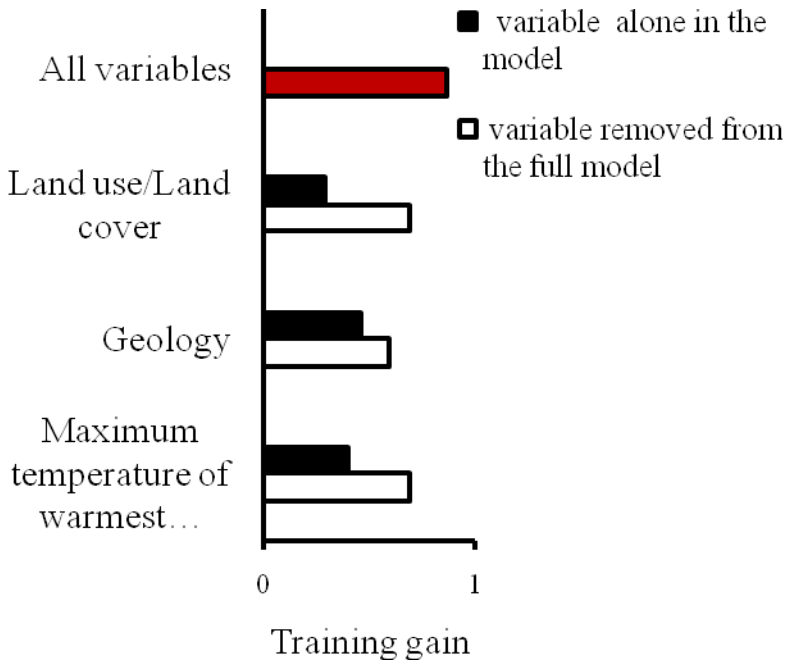
Appendix 3w. *Cloeotis percivali*.



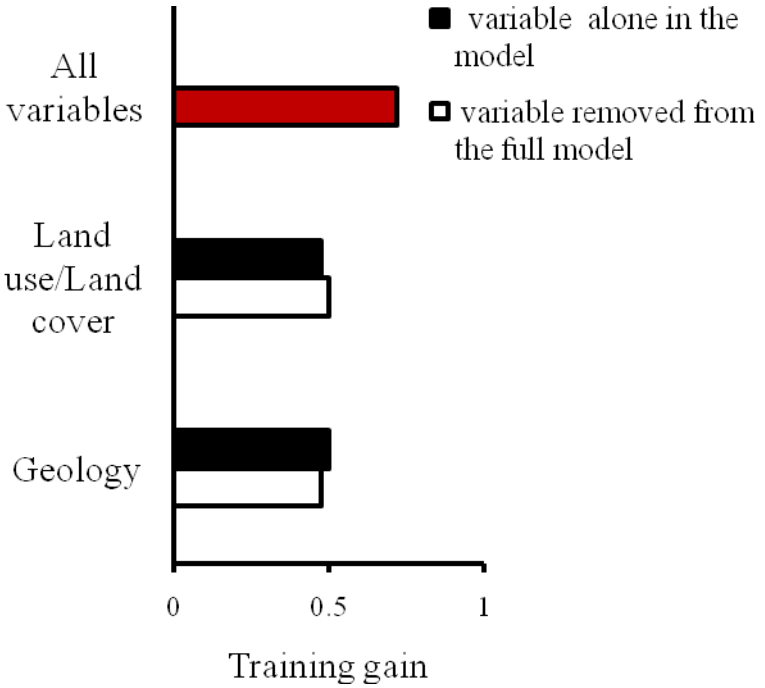
Appendix 3x. *Eptesicus hottentotus*.



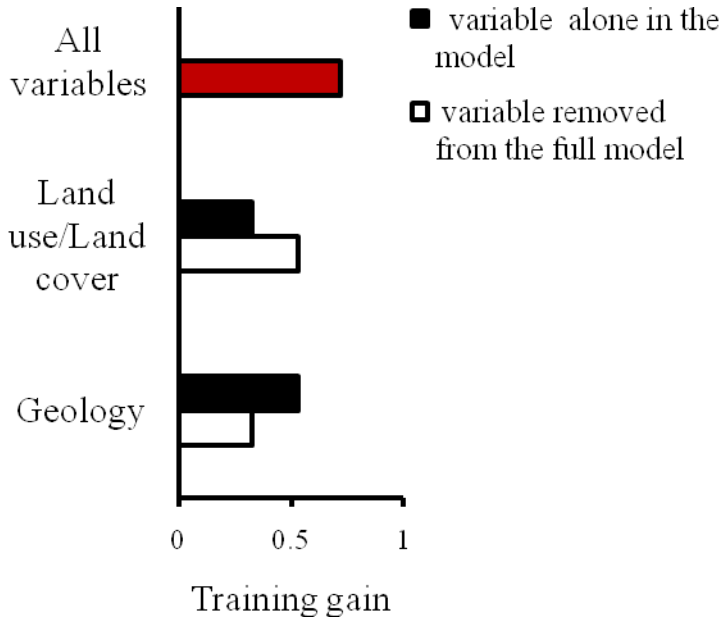
Appendix 3y. *Miniopterus natalensis*.



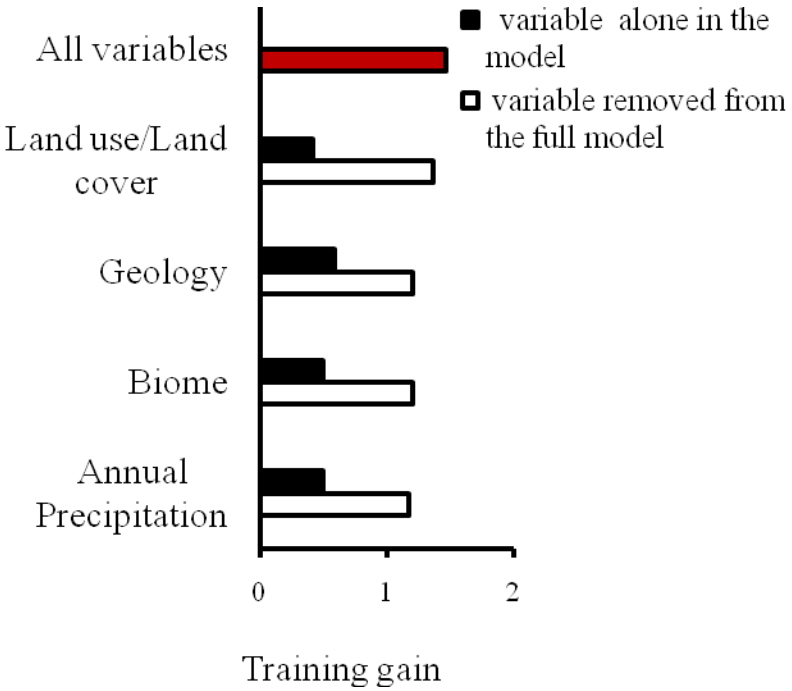
Appendix 3z. *Myotis tricolor*.



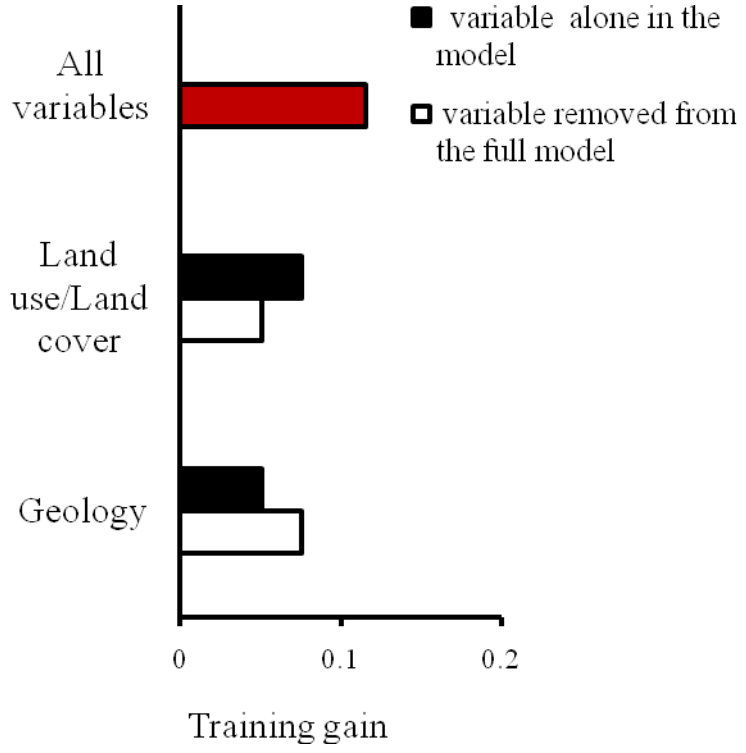
Appendix 3aa. *Rhinolophus darlingi*.



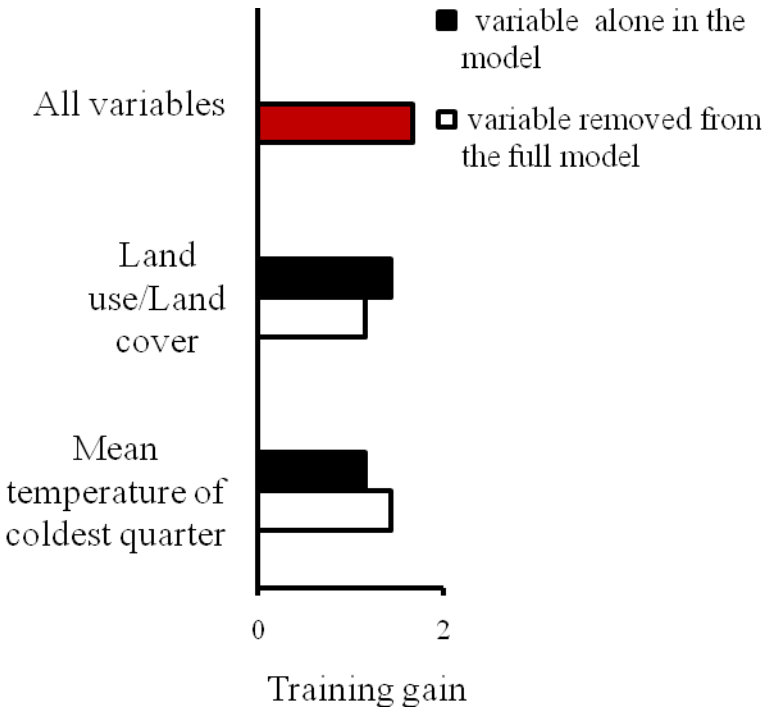
Appendix 3ab. *Sauromys petrophilus*.



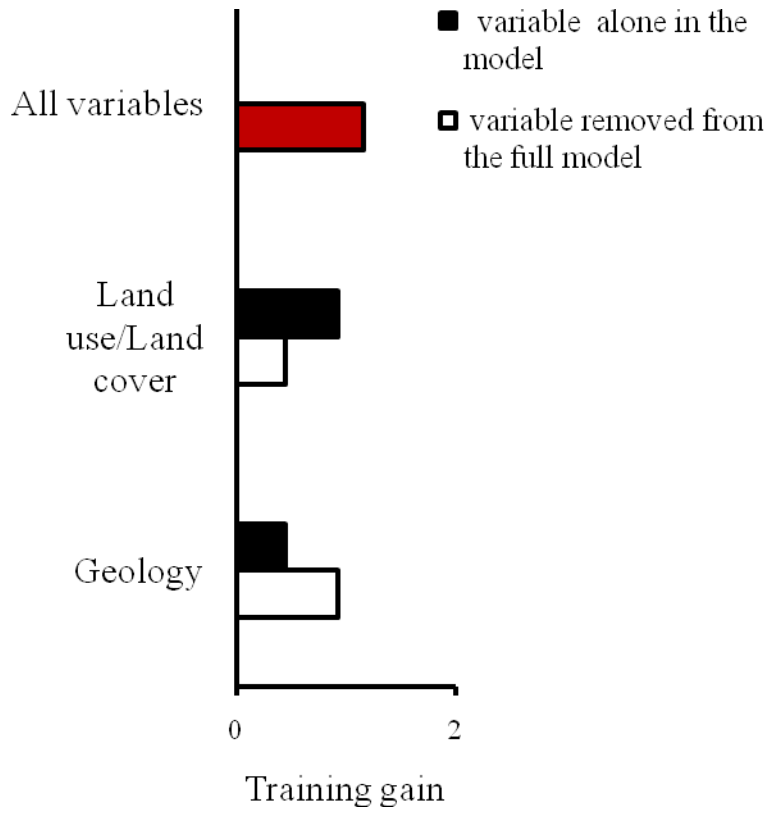
Appendix 3ac. *Rousettus aegyptiacus*.



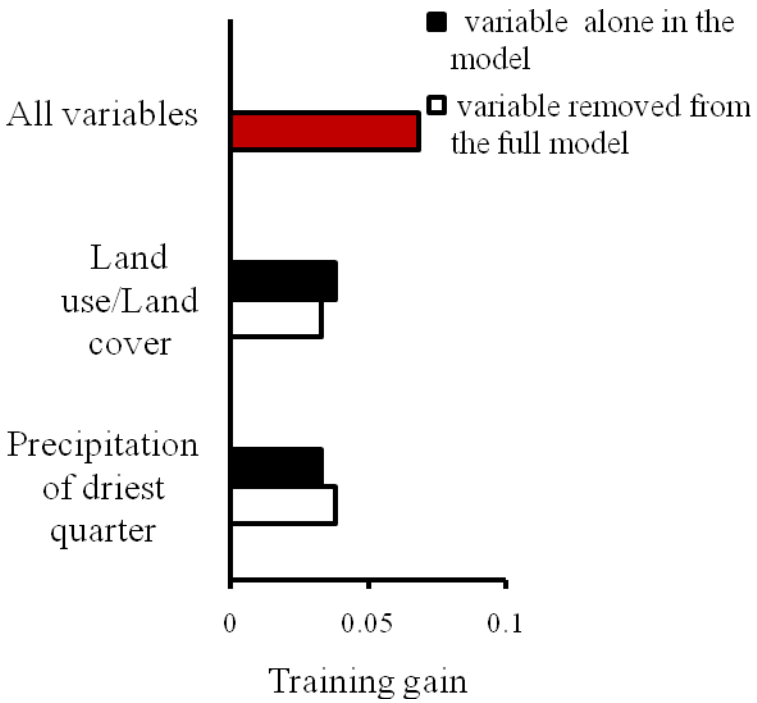
Appendix 3ad. *Neoromicia capensis*.



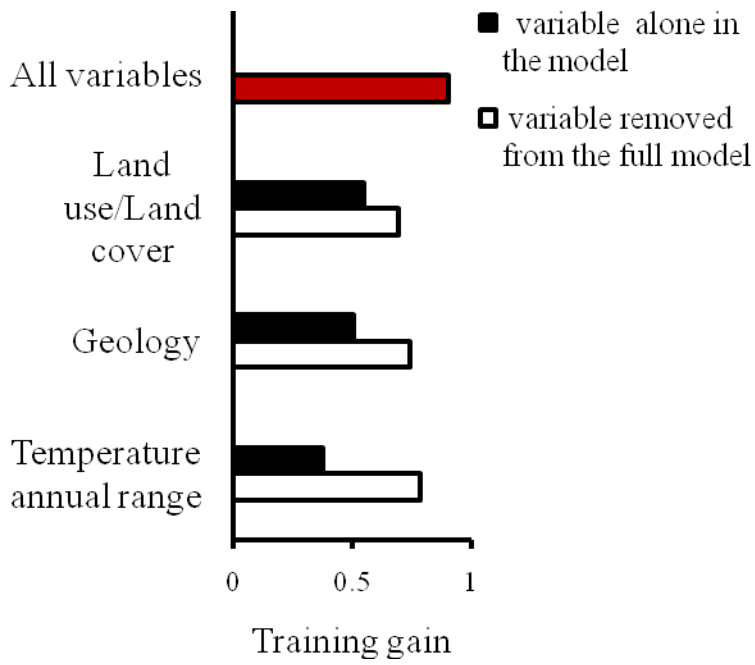
Appendix 3ae. *Neoromicia zuluensis*.



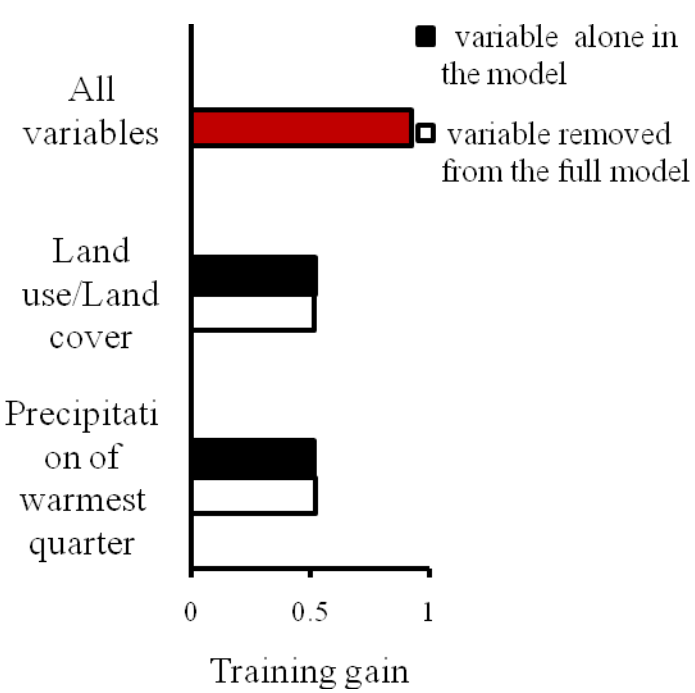
Appendix 3af. *Rhinolophus denti*.



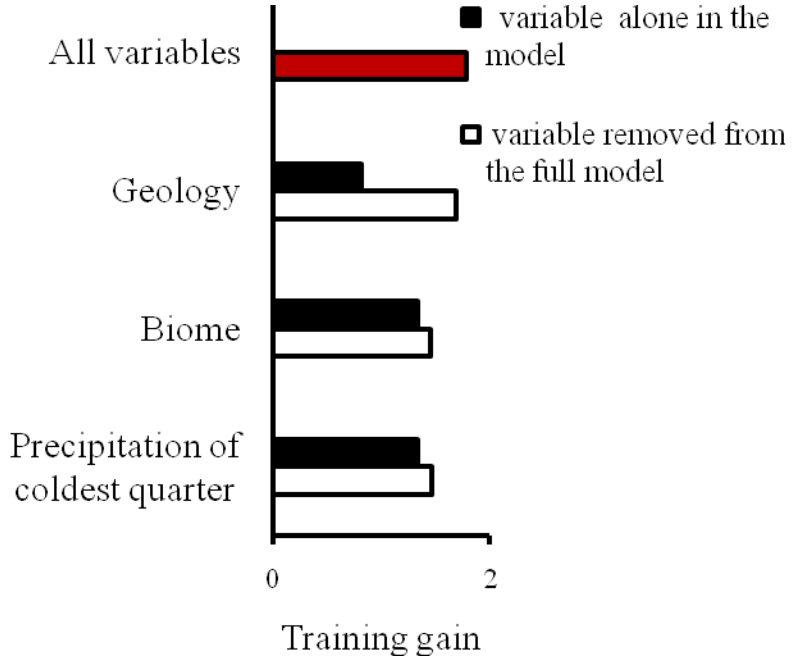
Appendix 3ag. *Tadarida aegyptiaca*.



Appendix 3ah. *Taphozous mauritianus*.



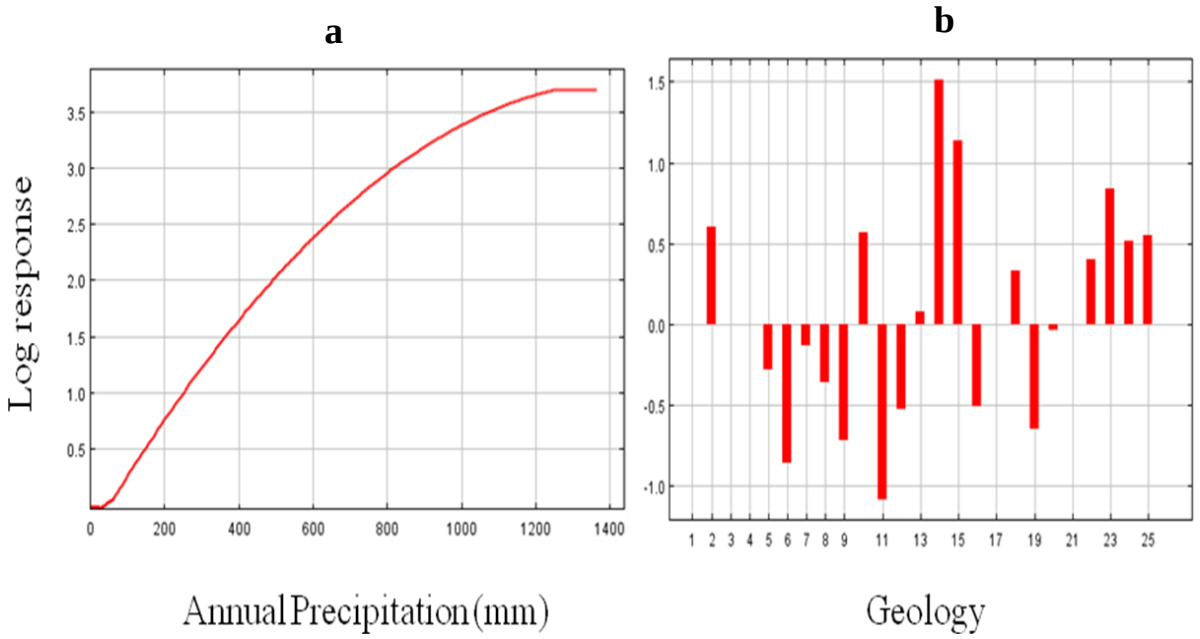
Appendix 3ai. *Myotis welwitschii*.



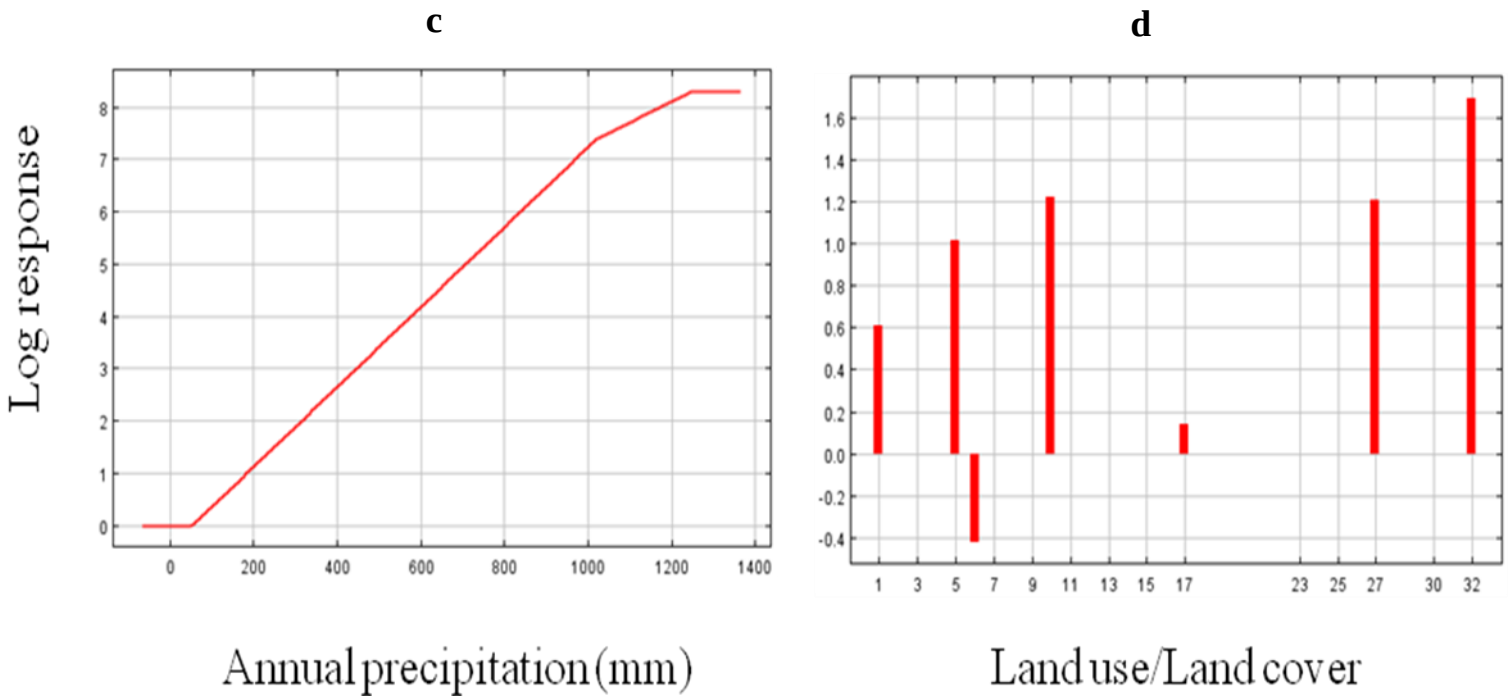
Appendix 3aj. *Rhinolophus capensis*.

Appendix 4

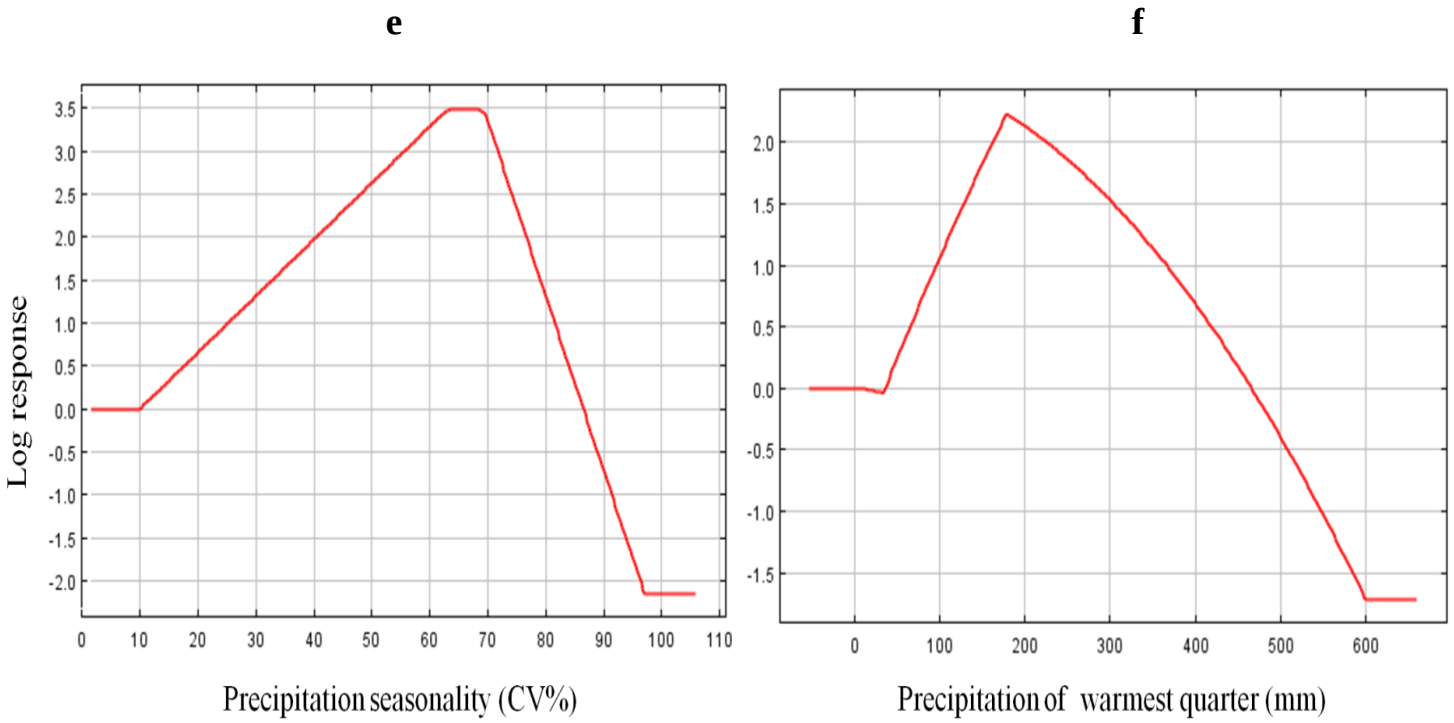
The log response of different South African bat species to precipitation, temperature, and biophysical (i.e., geology, land use/land cover, and biome) variables when all locality records for each bat species were employed to build the final model (i.e., model with the least number of significant predictor variables).



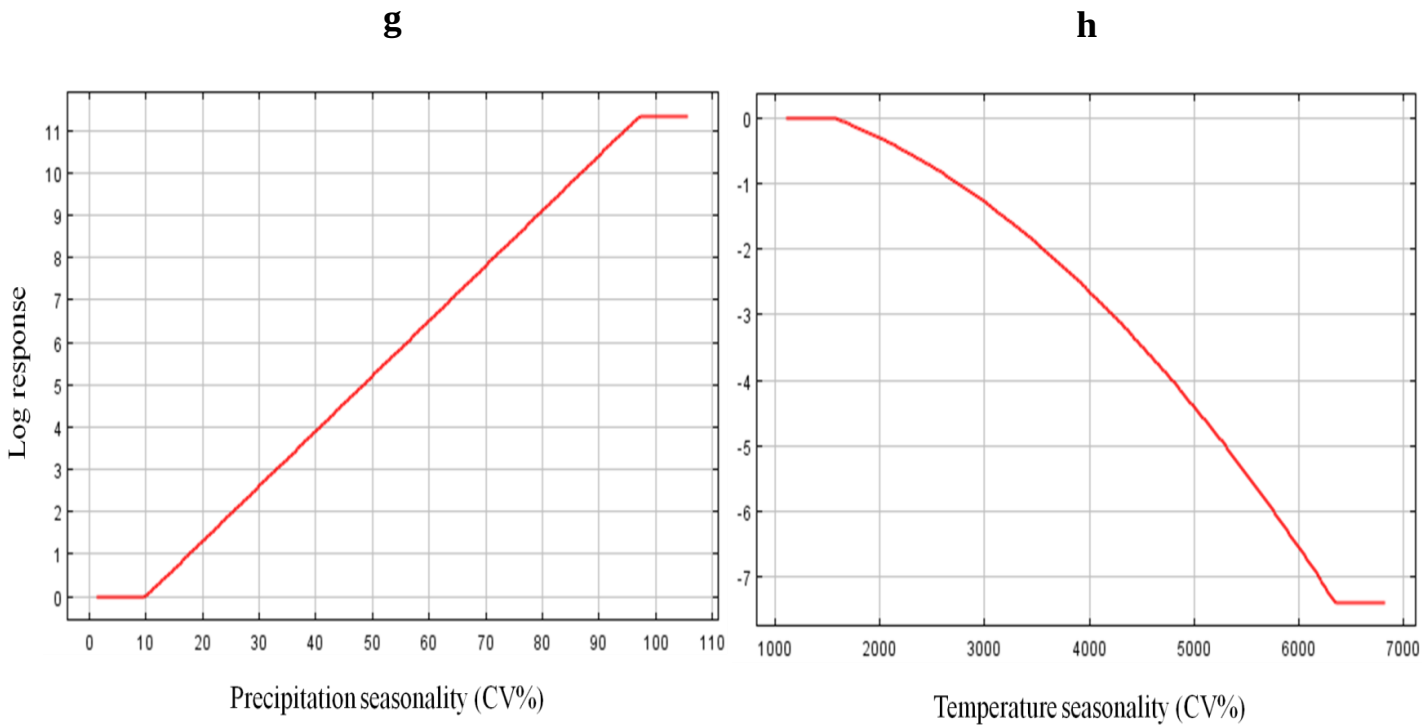
Appendices 4a and 4b. MaxEnt prediction illustrates the log response of *Rhinolophus clivosus* to (a) annual precipitation; and (b) geology, when all locality records were used to build the final model. The geology codes are displayed in Table 4.



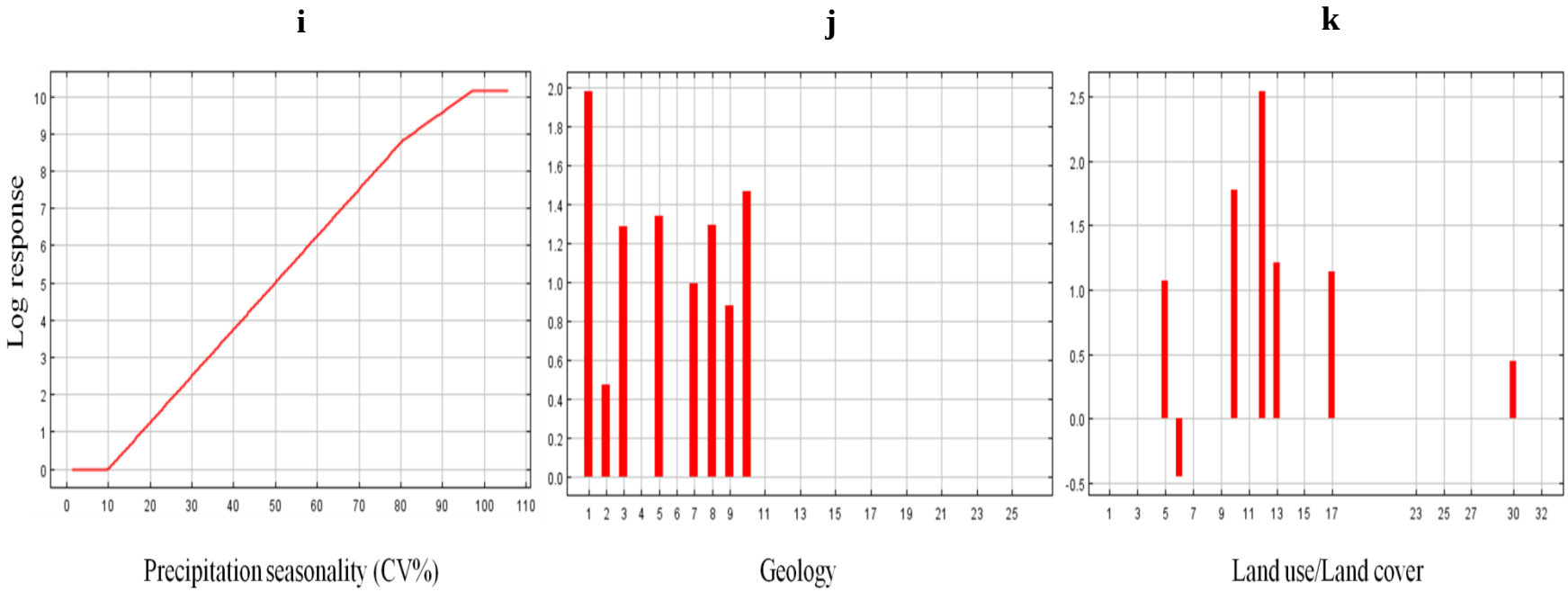
Appendices 4c and 4d. The log response of *Pipistrellus hesperidus* to (c) annual precipitation and (d) land use/land cover when all locality records were used to build the final model. Land use/land cover codes are displayed in Table 3.



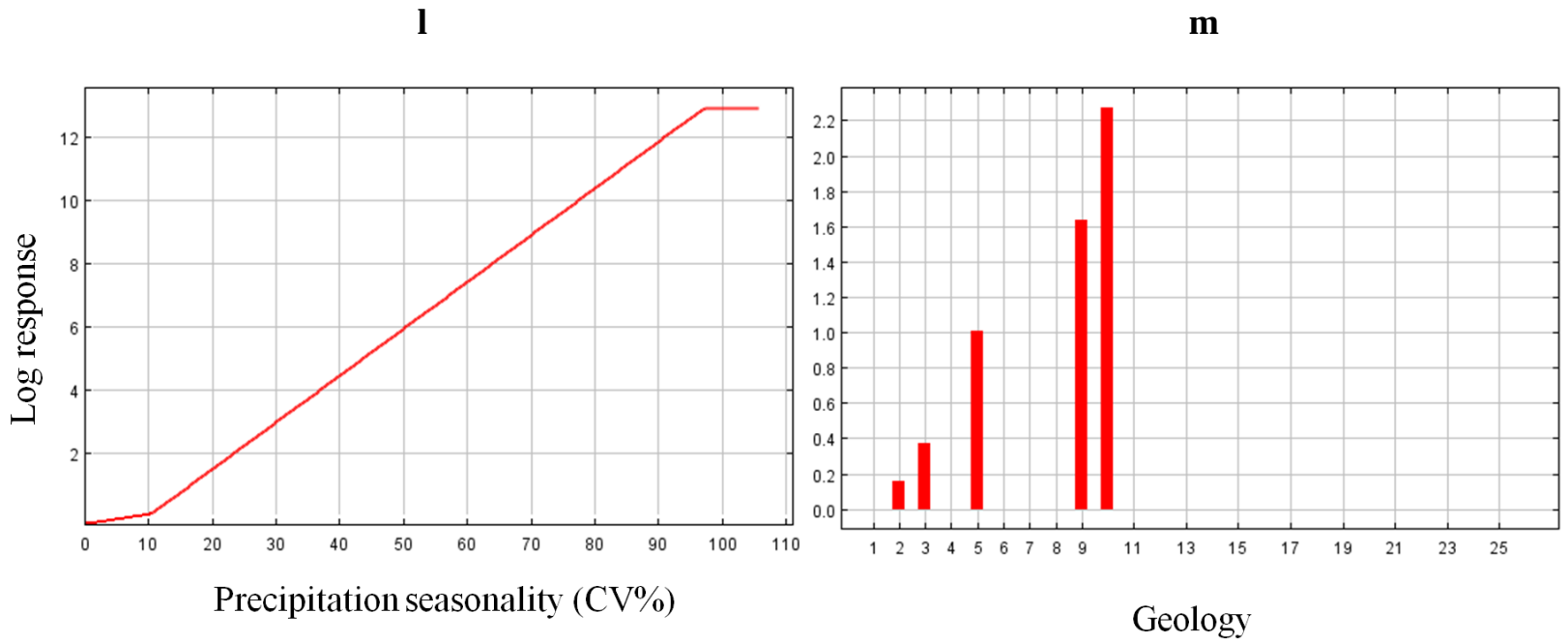
Appendices 4e and 4f. The log response of *Eidolon helvum* to (e) precipitation seasonality and (f) precipitation of warmest quarter when all locality records were used to build the final model. Precipitation seasonality (Coefficient of Variation) is the standard deviation of the monthly precipitation estimates expressed as a percentage of the mean of those estimates (i.e., the annual mean).



Appendices 4g and 4h. The log response of *Mops midas* to (g) precipitation seasonality and (h) temperature seasonality when all locality records were used to build the final model. Precipitation seasonality (Coefficient of Variation) is the standard deviation of the monthly precipitations estimates expressed as a percentage of the mean of those estimates (i.e., the annual mean). Temperature seasonality (Coefficient of Variation) is the standard deviation of the monthly temperature estimates expressed as a percentage of the mean of those estimates (i.e., the annual mean).

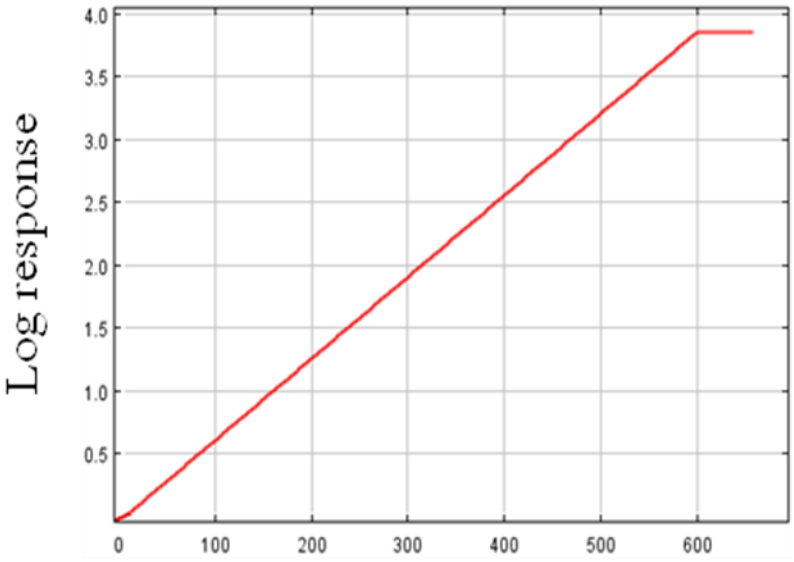


Appendices 4i, 4j, 4k. The log response of *Pipistrellus rusticus* to (i) precipitation seasonality, (j) geology and (k) land use/land cover when all locality records were used to build the final model. Precipitation seasonality (Coefficient of Variation) is the standard deviation of the monthly precipitations estimates expressed as a percentage of the mean of those estimates (i.e., the annual mean). Geology codes are exhibited in Table 4, Land use/land cover codes are displayed in Table 3.

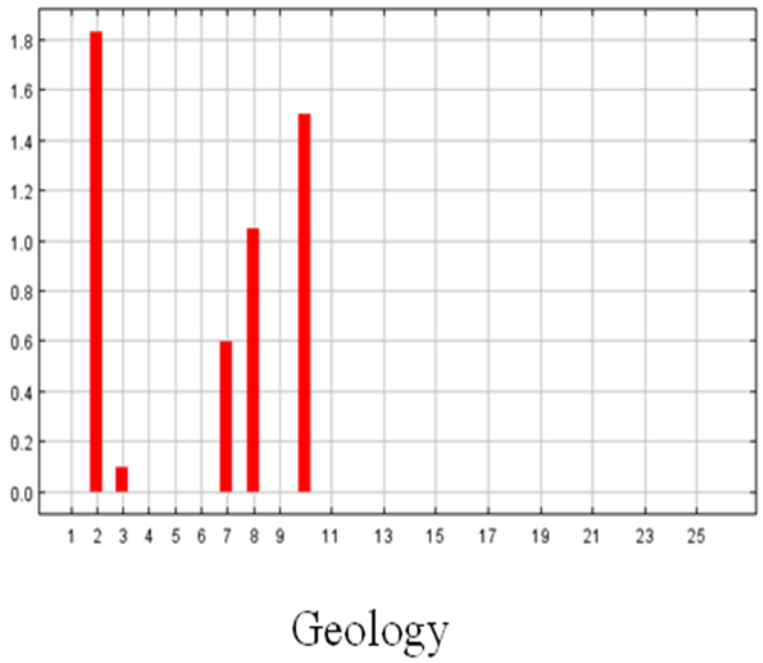


Appendices 4l and 4m. The log response of *Rhinolophus hildebrandtii* to (l) precipitation seasonality and (m) geology when all locality records were used to build the final model. Precipitation seasonality (Coefficient of Variation) is the standard deviation of the monthly precipitations estimates expressed as a percentage of the mean of those estimates (i.e., the annual mean). Geology codes are portrayed in Table 4.

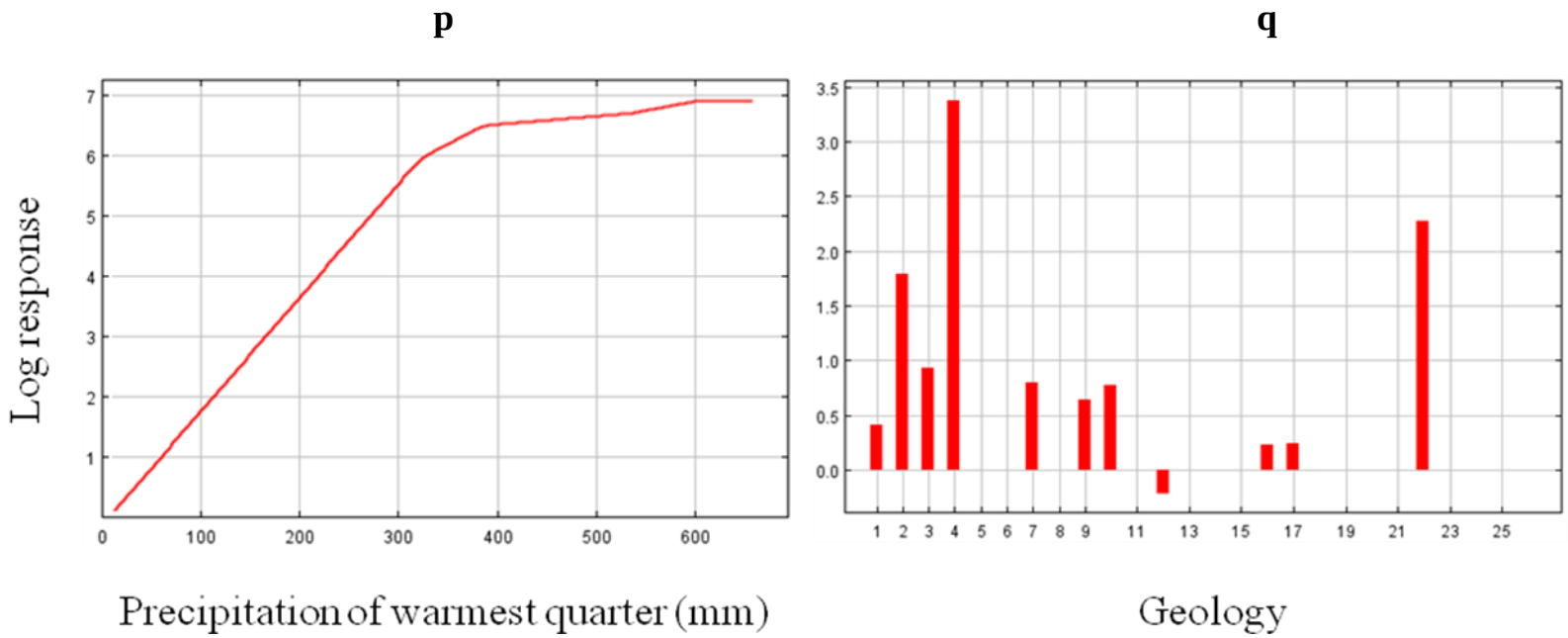
n



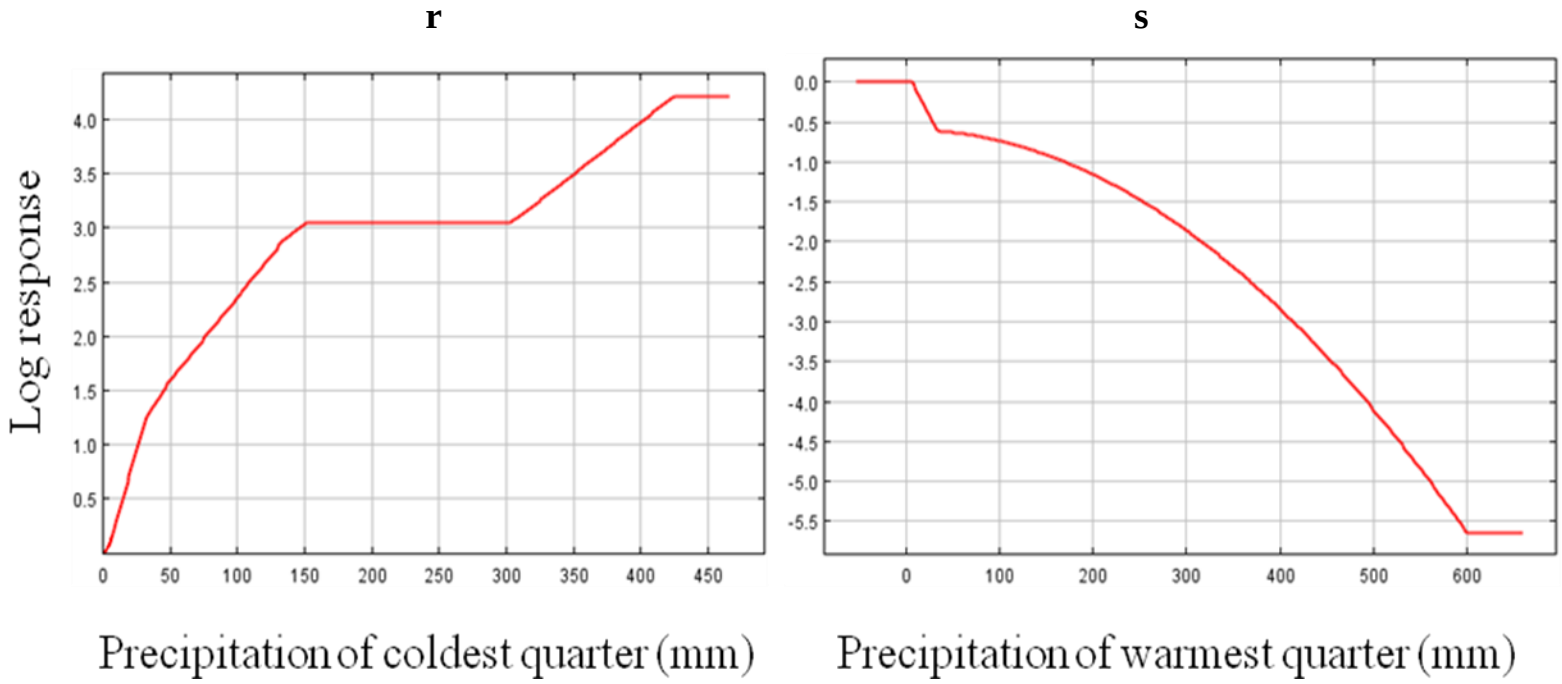
o



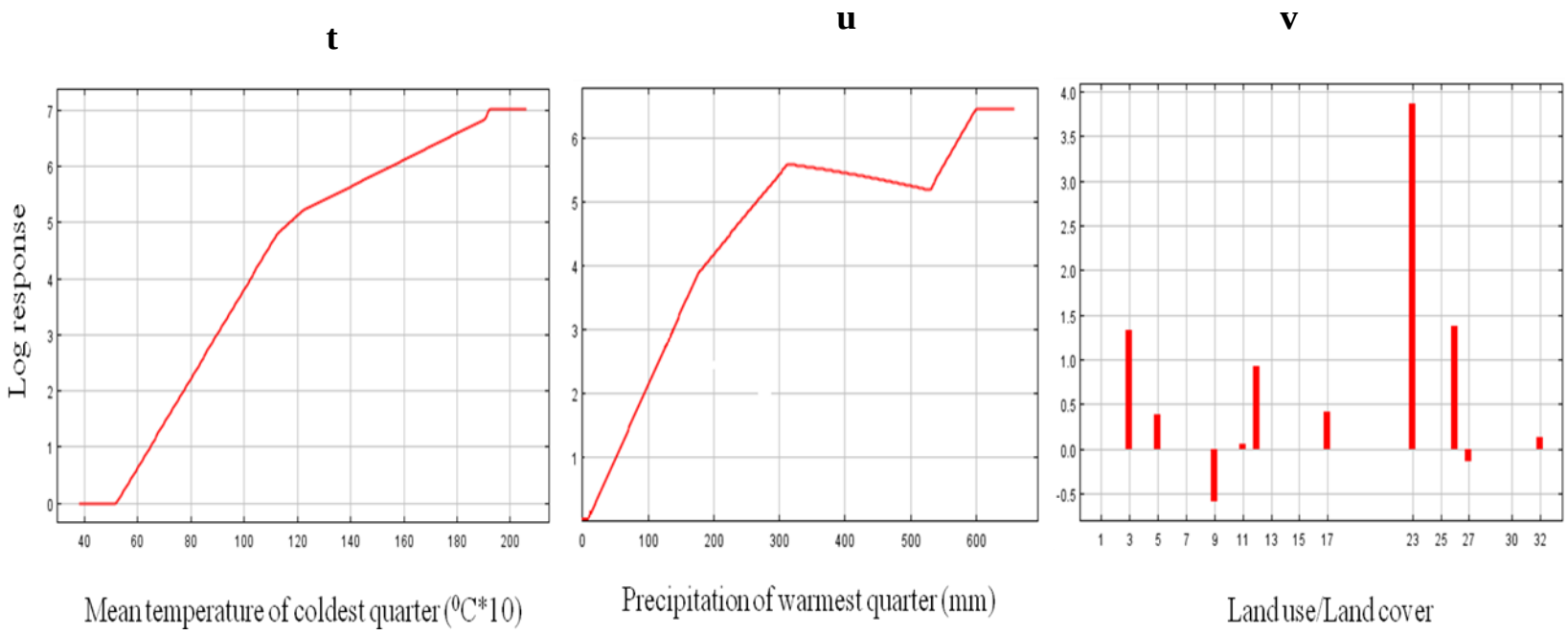
Appendices 4n and 4o. The log response of *Rhinolophus blasii* to (n) precipitation of warmest quarter and (o) geology when all locality records were used to build the final model. Geology codes are exhibited in Table 4.



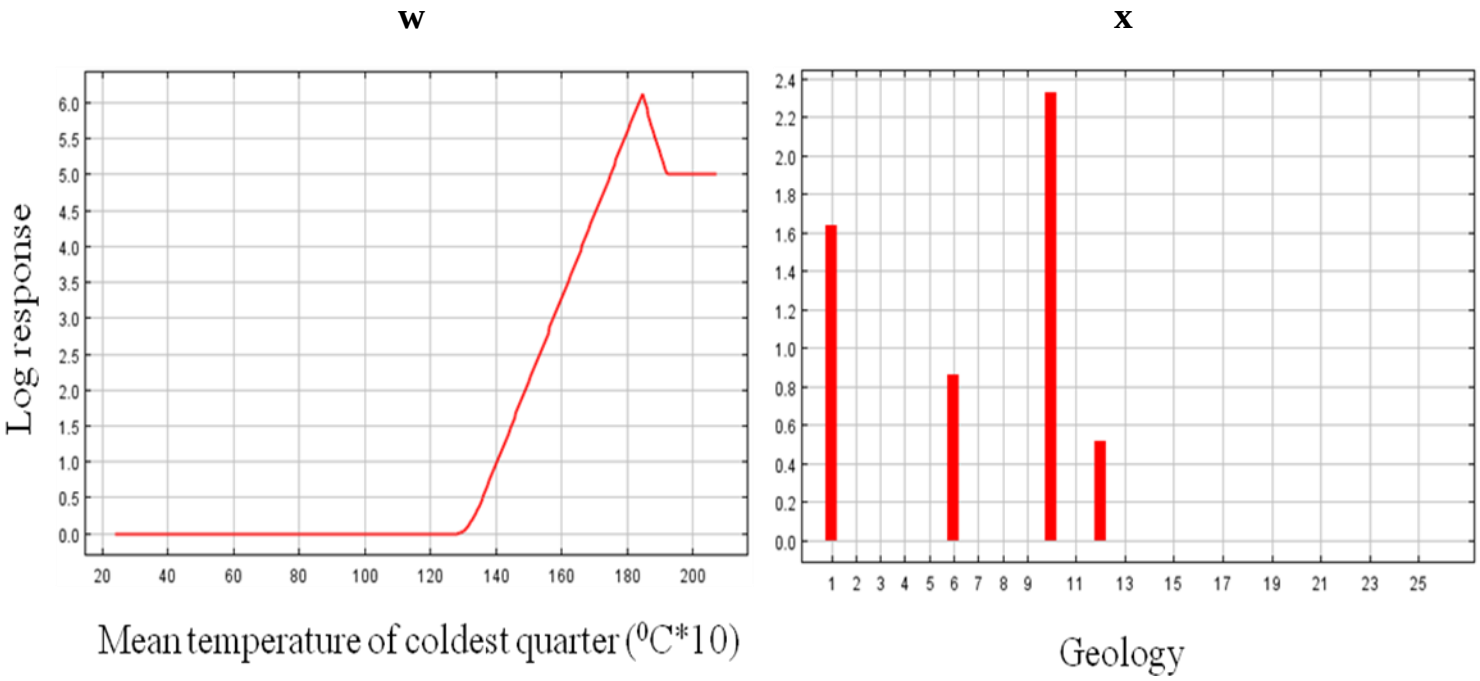
Appendices 4p and 4q. The log response of *Rhinolophus simulator* to (p) precipitation of warmest quarter and (q) geology when all locality records were used to build the final model. Geology codes are displayed in Table 4.



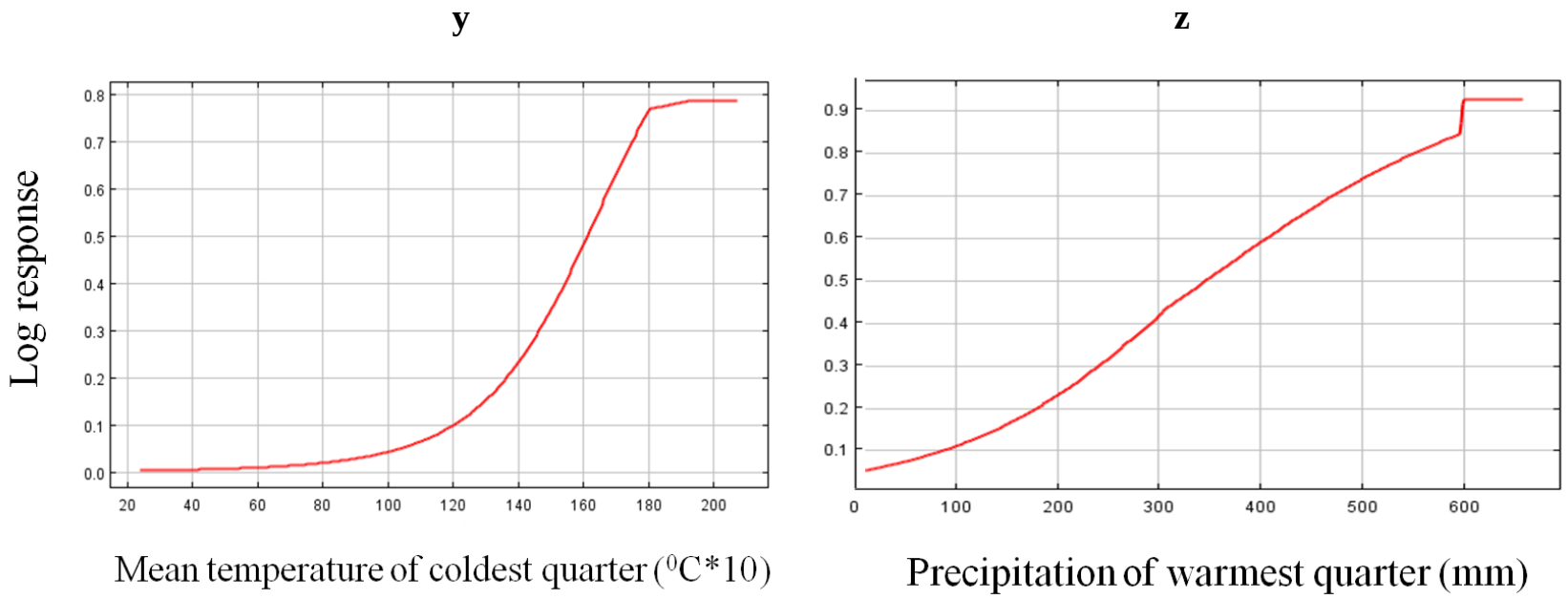
Appendix 4r and 4s. The log response of *Neoromicia melckorum* to (r) precipitation of coldest quarter and (s) precipitation of warmest quarter when all locality records were used to build the final model.



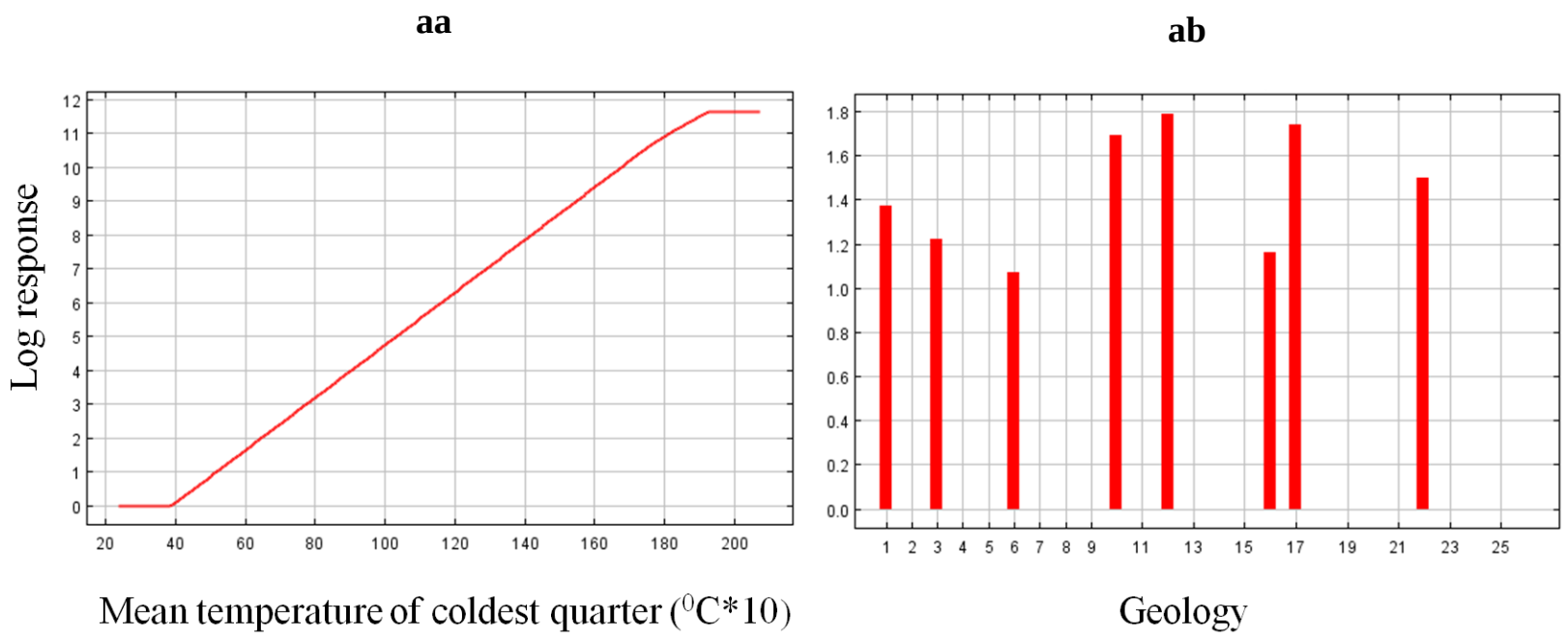
Appendices 4t, 4u, and 4v. The log response of *Scotophilus dinganii* to (t) mean temperature of coldest quarter, (u), precipitation of warmest quarter and (v) land use/land cover when all locality records were used to build the final model. Land use/land cover codes are displayed in Table 3.



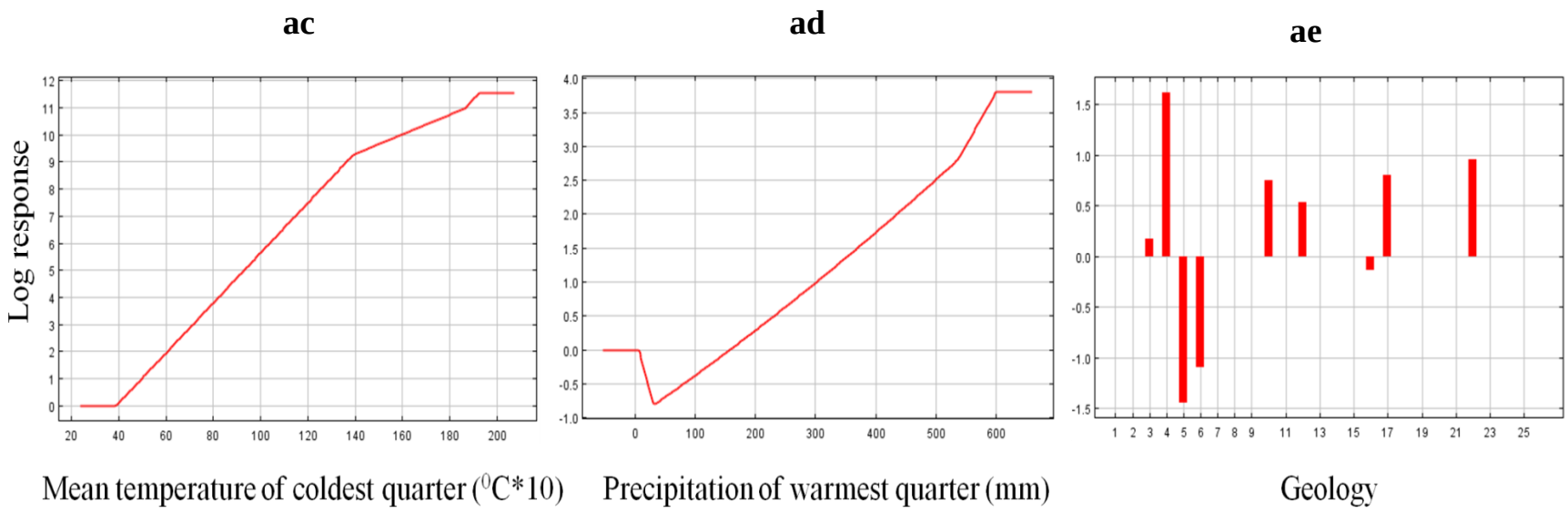
Appendices 4w and 4x. The log response of *Scotophilus viridis* to (w) means temperature of coldest quarter and (x) geology when all locality records were used to build the final model. Geology codes are portrayed in Table 4.



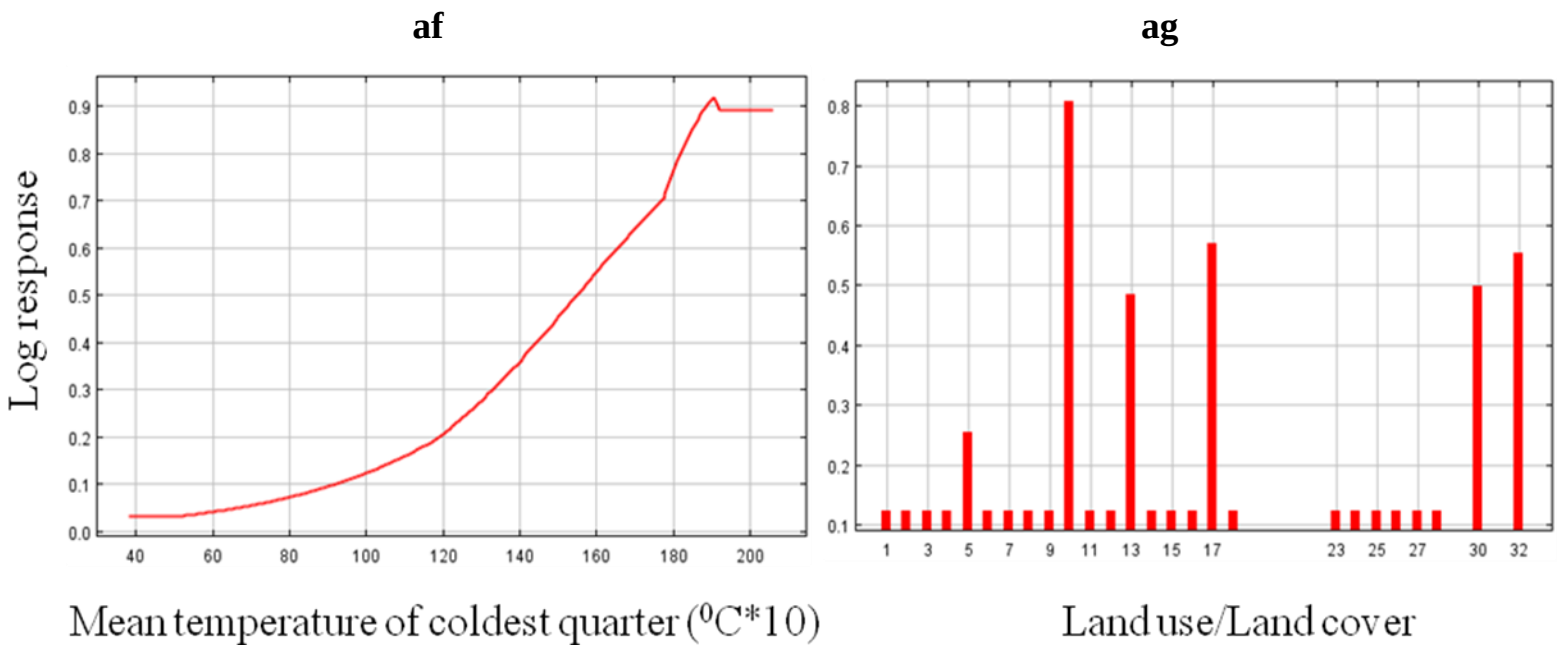
Appendices 4y and 4z. The log response of *Chaerephon pumilus* to (y) mean temperature of coldest quarter and (z) precipitation of warmest quarter when all locality records were used to build the final model.



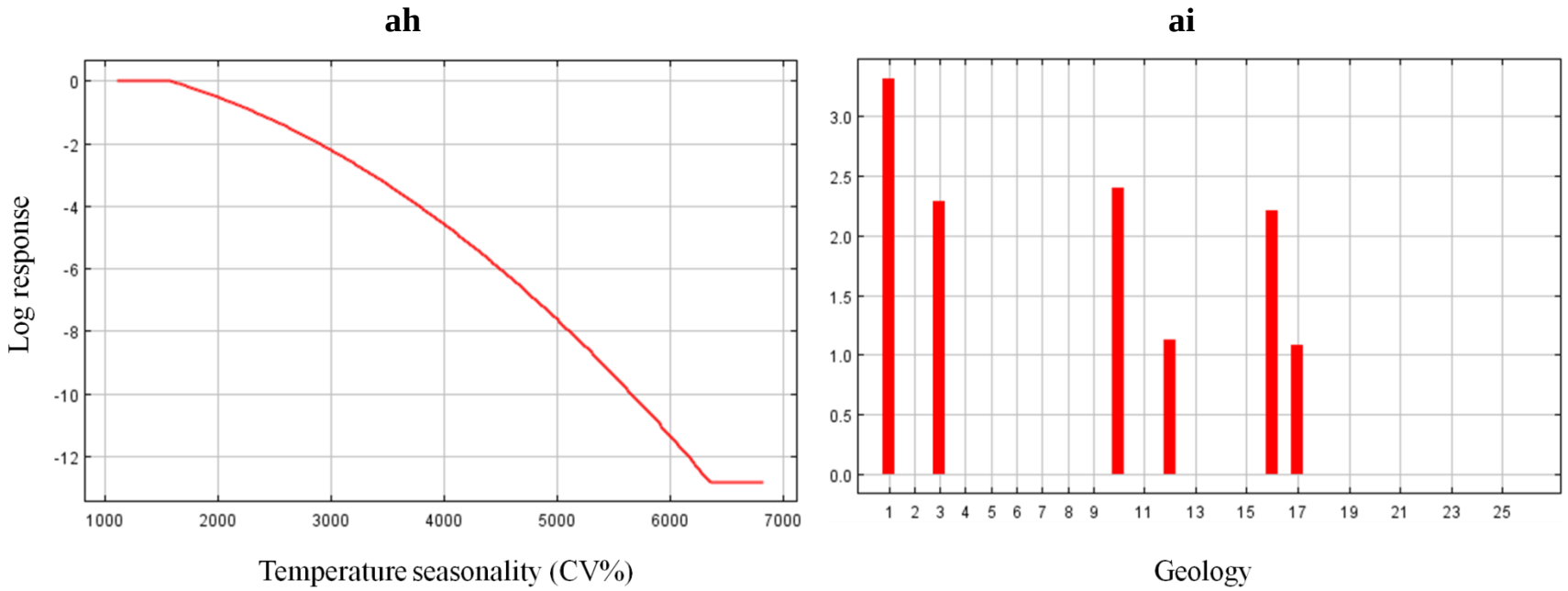
Appendices 4aa and 4ab. The log response of *Mops condylurus* to (aa) mean temperature of coldest quarter and (ab) geology when all locality records were used to build the final model. Geology codes are exhibited in Table 4.



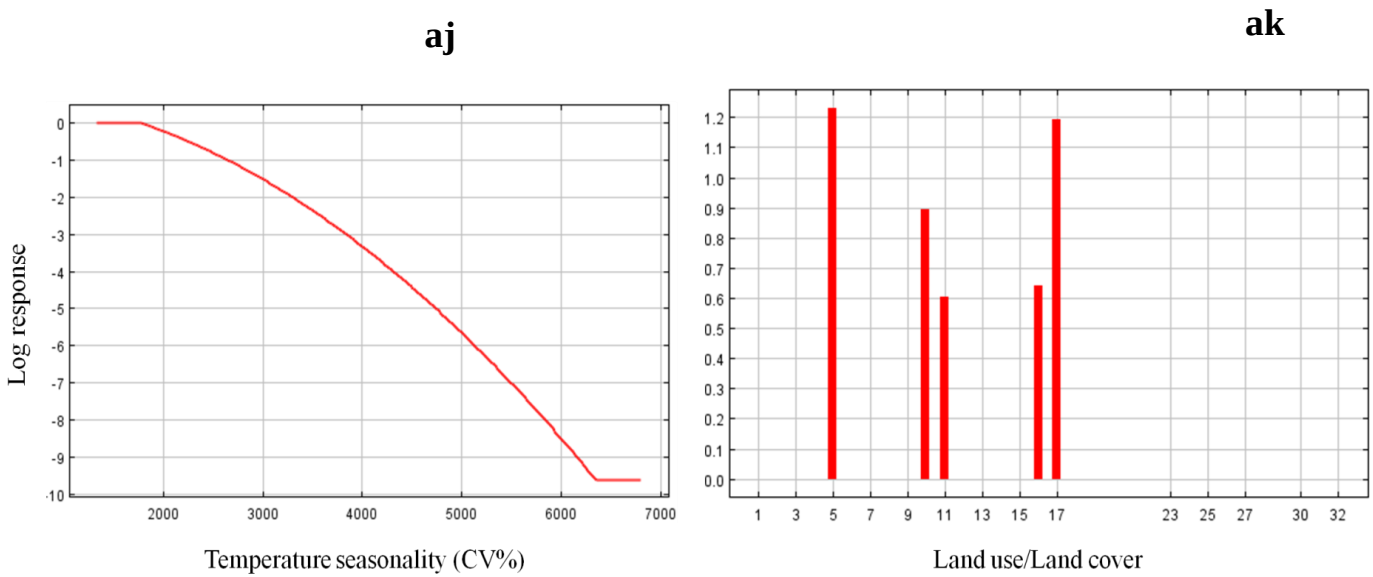
Appendices 4ac, 4ad, and 4ae. The log response of *Hipposideros caffer* to (ac) mean temperature of coldest quarter, (ad) precipitation of warmest quarter, and (ae) geology when all locality records were used to build the final model. Geology codes are displayed in Table 4.



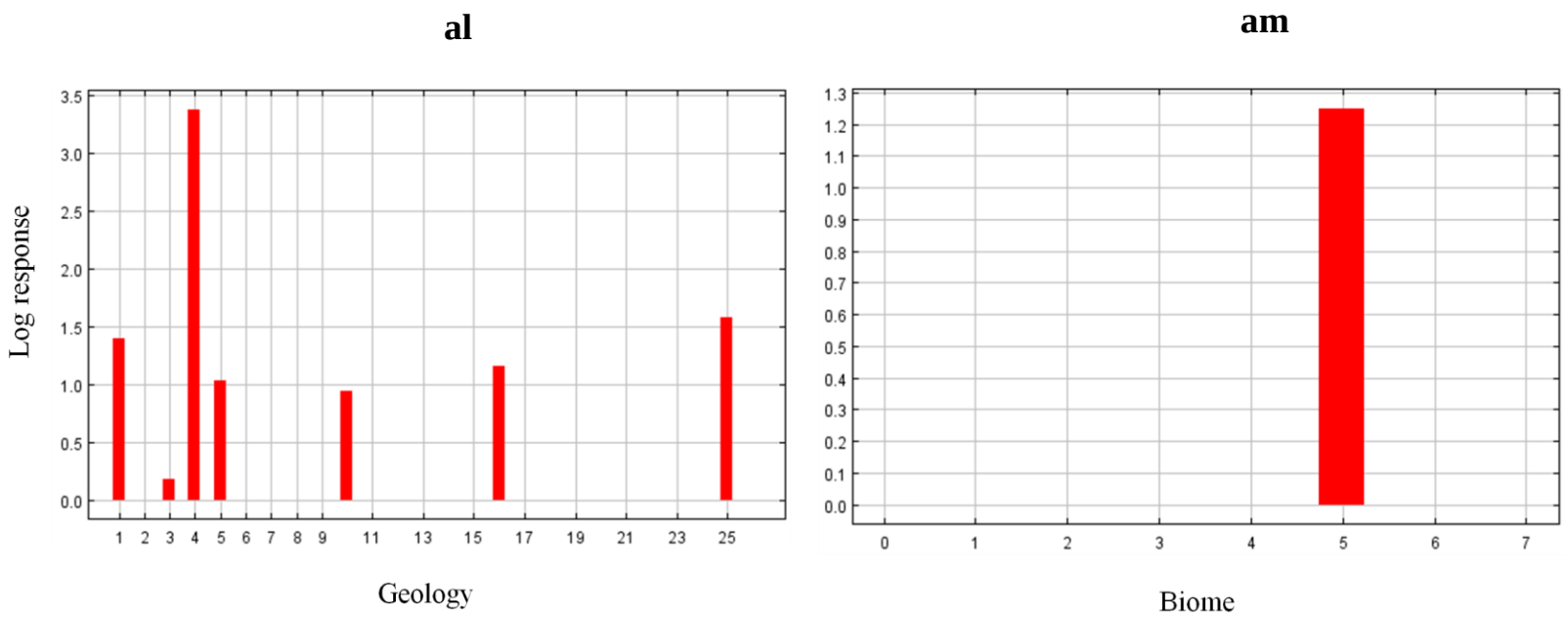
Appendices 4af and 4ag. The log response of *Epomophorus crypturus* to (af) mean temperature of coldest quarter and (ag) land use/land cover when all locality records were used to build the final model. Land use/land cover codes are listed in Table 3.



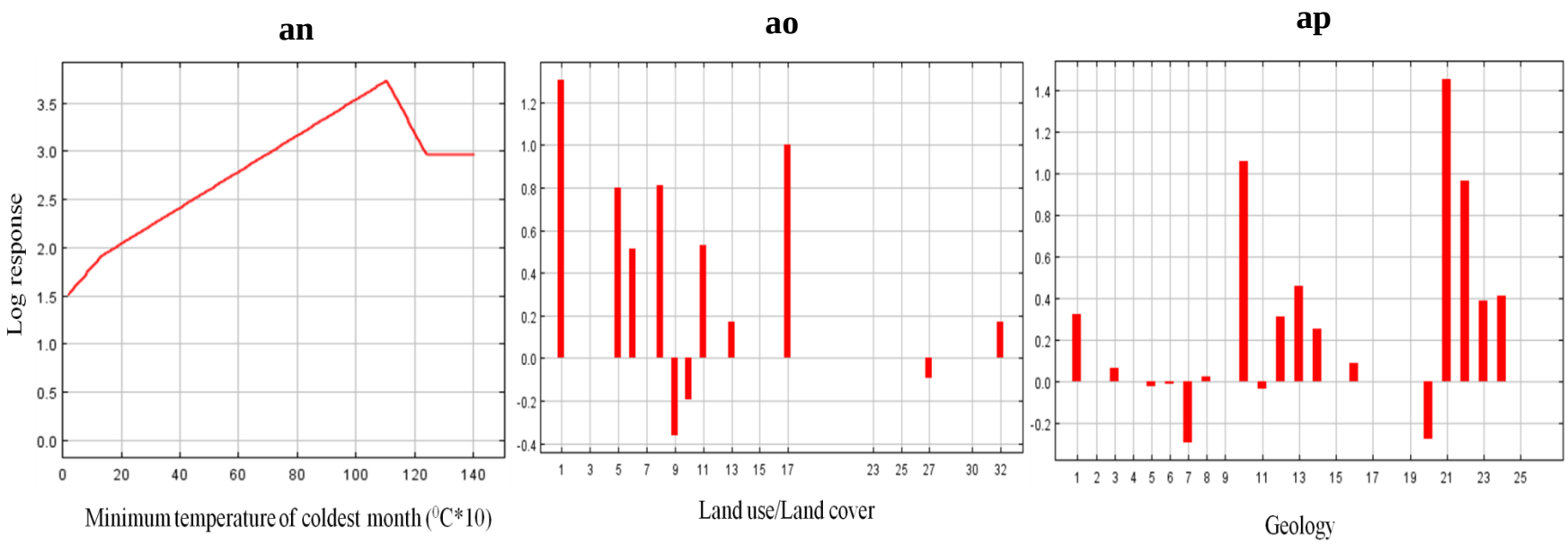
Appendices 4ah and 4ai. The log response of *Rhinolophus swinnyi* to (ah) temperature seasonality and (ai) geology when all locality records were used to build the final model. Geology codes are furnished in Table 4. Temperature seasonality (Coefficient of Variation) refers to the standard deviation of the monthly temperature estimates expressed as a percentage of the mean of those estimates (i.e., the annual mean).



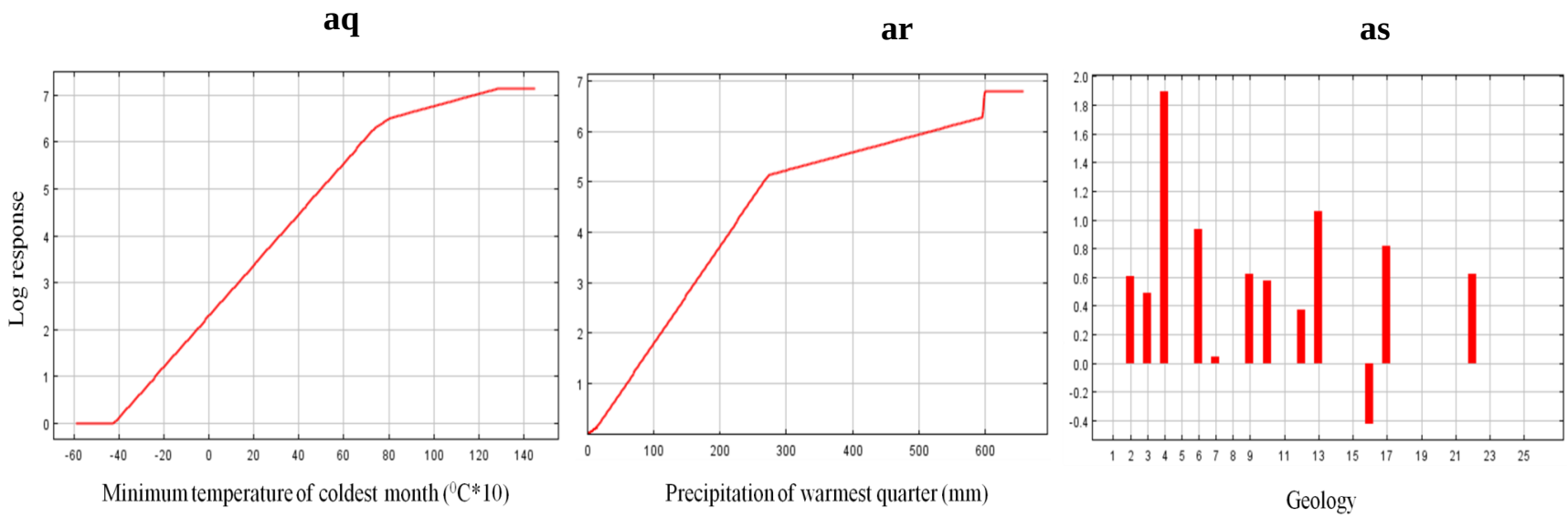
Appendices 4aj and 4ak. The log response of *Kerivoula lanosa* to (aj) temperature seasonality and (ak) land use/land cover when all locality records were used to build the final model. Temperature seasonality (Coefficient of Variation) is the standard deviation of the monthly temperature estimates expressed as a percentage of the mean of those estimates (i.e., the annual mean). Land use/land cover codes are exhibited in Table 3.



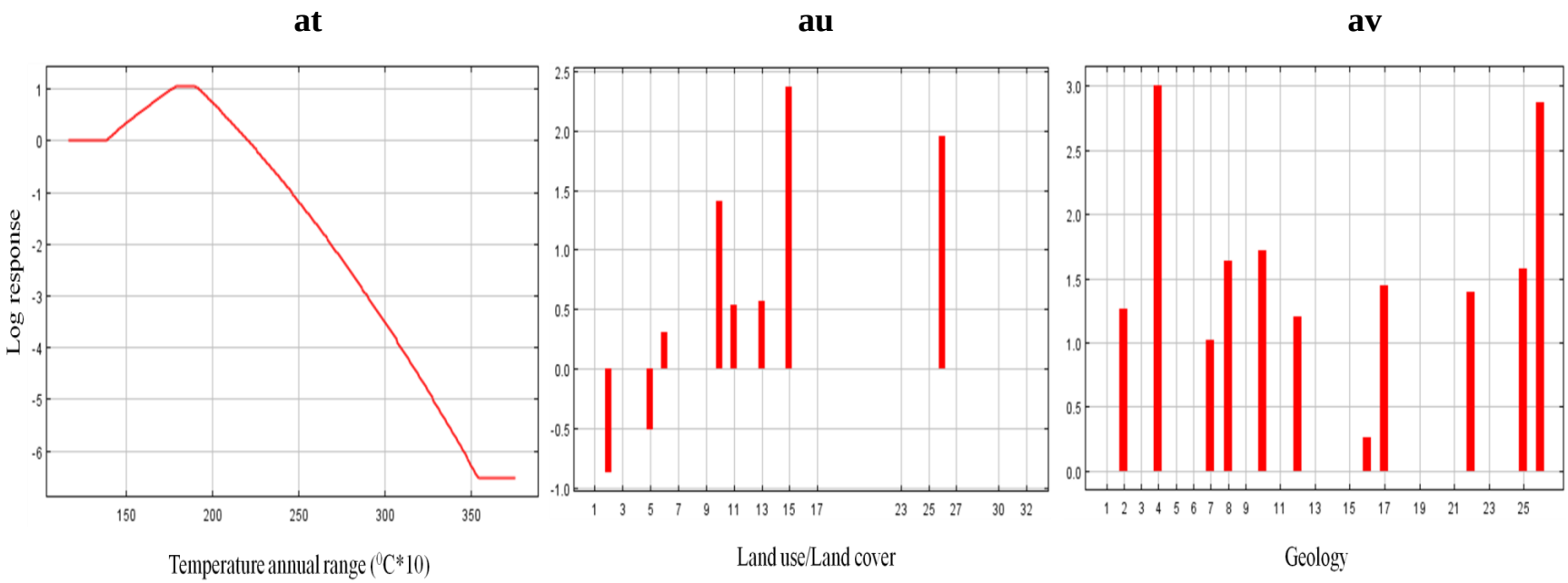
Appendices 4al and 4 am. The log response of *Kerivoula lanosa* to (al) geology and (am) biome when all locality records were used to build the final model. Geology and biome codes are displayed in Table 4 and Table 2, respectively.



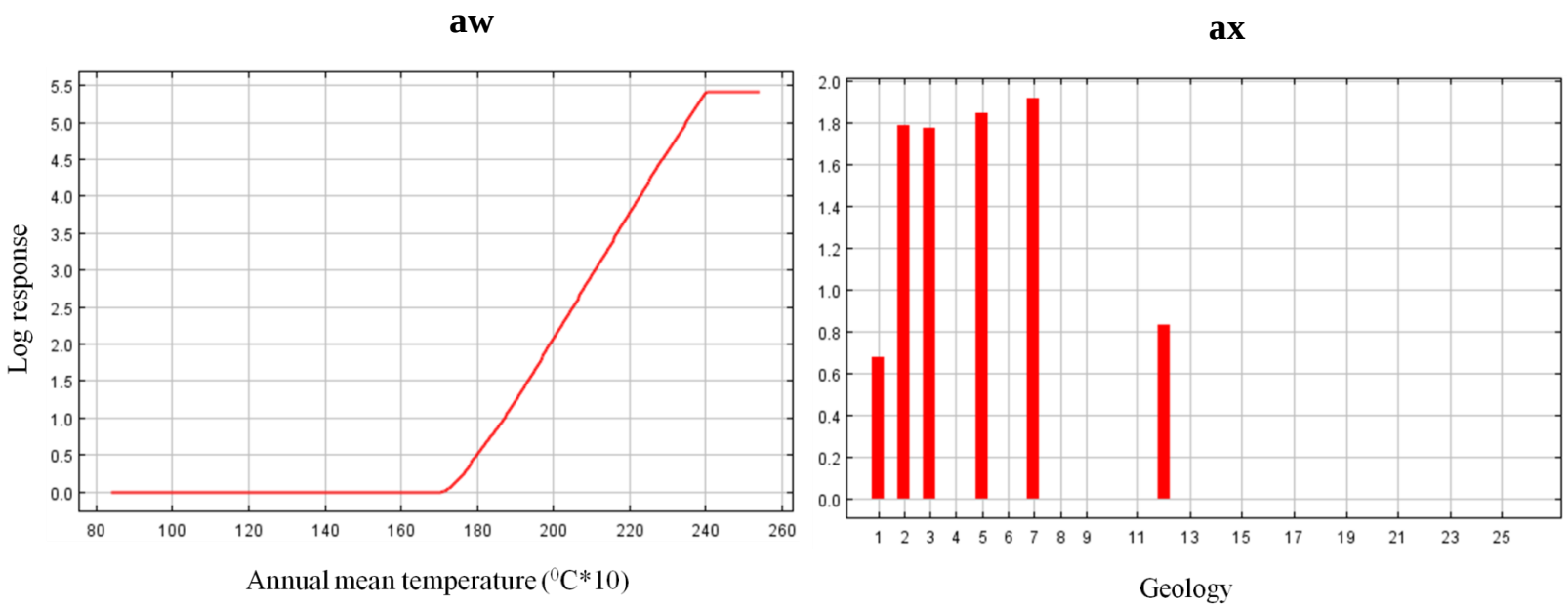
Appendices 4an, 4ao, and 4ap. The log response of *Nycteris thebaica* to (an) minimum temperature of coldest month, (ao) land use/land cover and (ap) geology when all locality records were used to build the final model. Land use/land cover and geology codes are exhibited in Table 3 and Table 4, respectively.



Appendices 4aq, 4ar, and 4as. The log response of *Neoromicia nana* to (aq) minimum temperature of coldest month, (ar) precipitation of warmest quarter and (as) geology when all locality records were used to build the final model. Geology codes are displayed in Table 4.

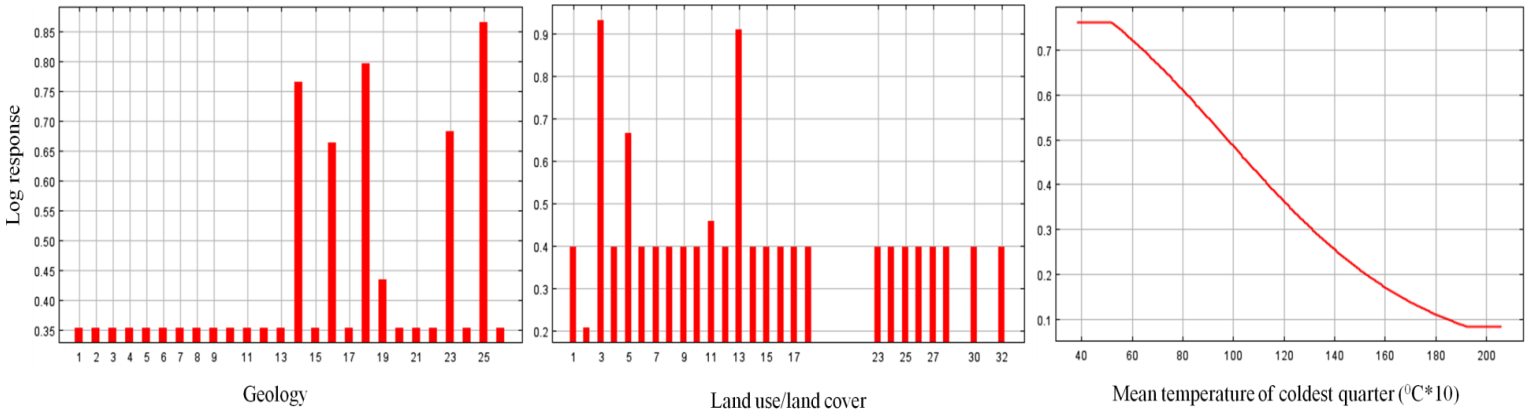


Appendices 4at, 4au, and 4av. The log response of *Miniopterus fraterculus* to (at) temperature annual range, (au) land use/land cover and (av) geology when all locality records were used to build the final model. Land use/land cover and geology codes are displayed in Table 3 and Table 4, respectively.

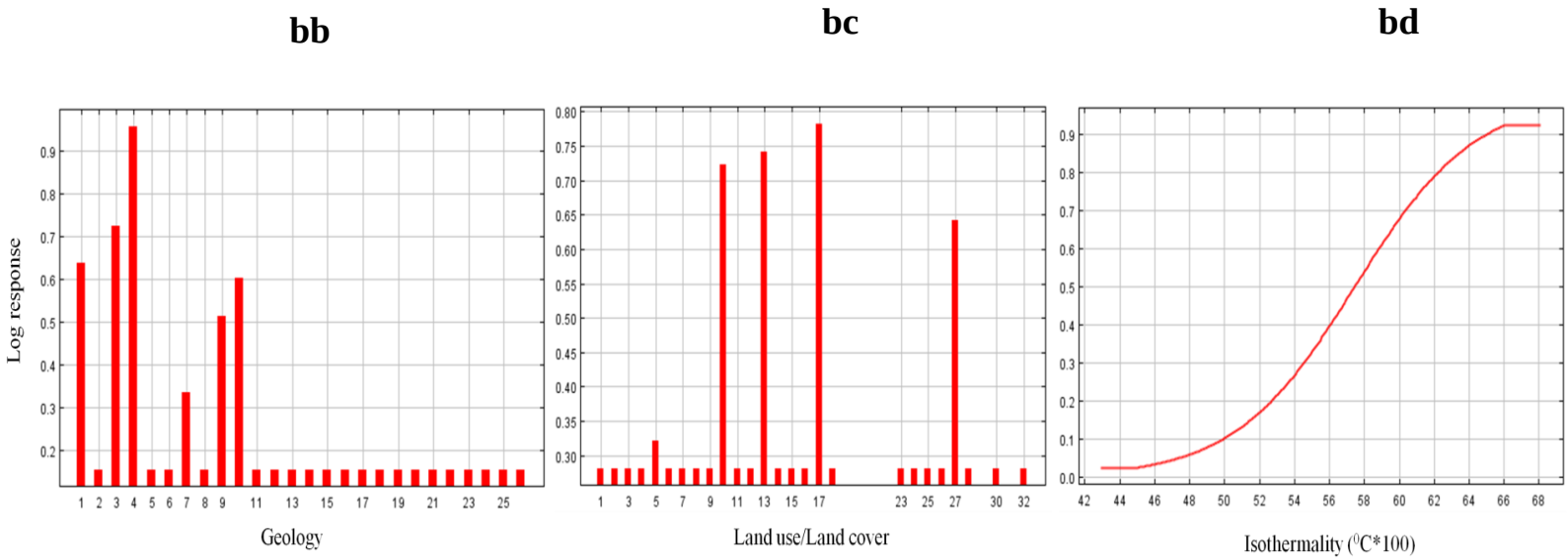


Appendices 4aw and 4ax. The log response of *Nycticeinops schlieffeni* to (aw) annual mean temperature and (ax) geology when all locality records were used to build the final model. Geology codes are displayed in Table 4.

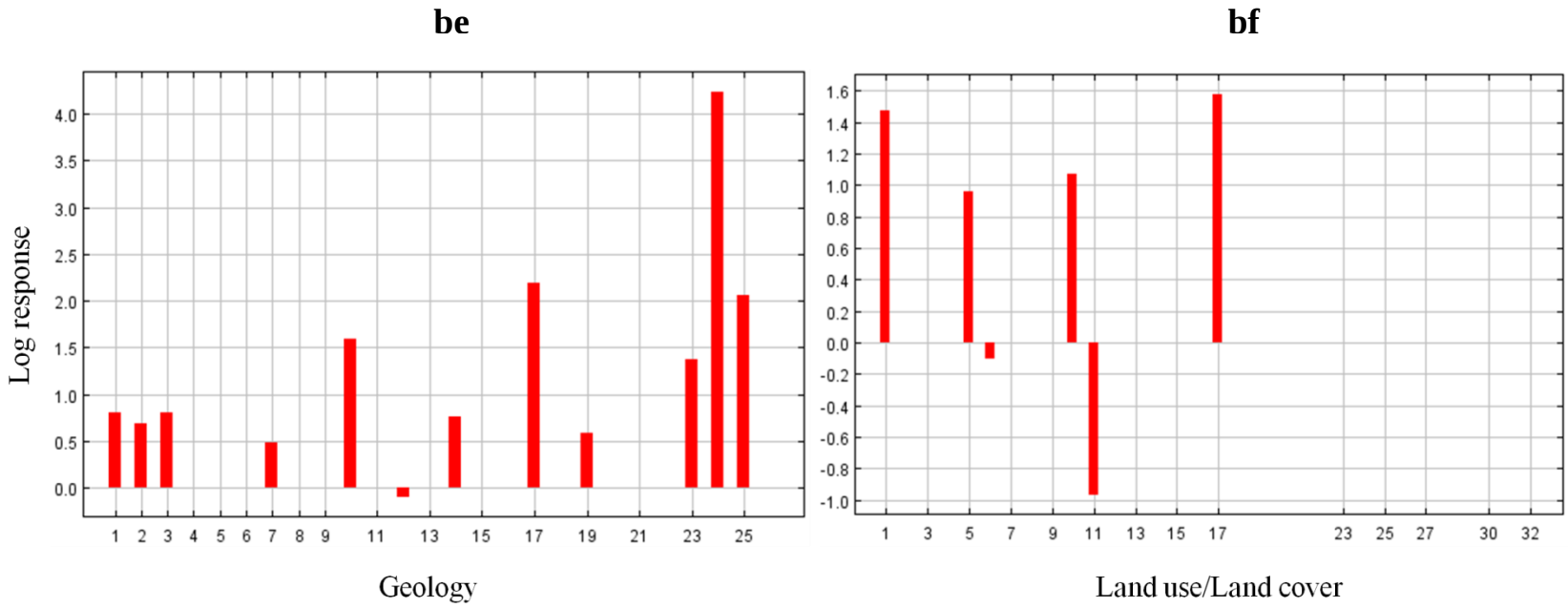
ay **az** **ba**



Appendices 4ay, 4az, and 4ba. The log response of *Cistugo lesueuri* to (ay) geology, (az) land use/land cover and (ba) mean temperature of coldest quarter when all locality records were used to build the final model. Geology and land use/land cover codes are exhibited in Table (4) and Table (3) respectively.

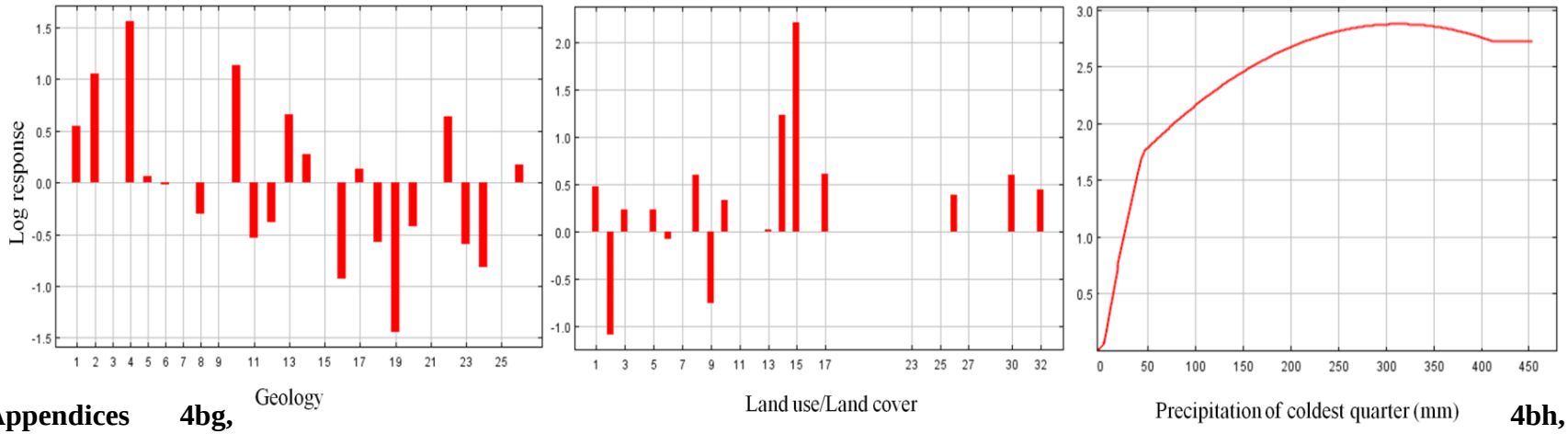


Appendices 4bb, 4bc, and 4bd. The log response of *Cloeotis percivali* to (bb) geology, (bc) land use/land cover and (bd) isothermality when all locality records were used to build the final model. Isothermality is denoted by the mean diurnal range divided by the annual temperature range. Geology and land use/land cover codes are displayed in Table 4 and Table 3 respectively.

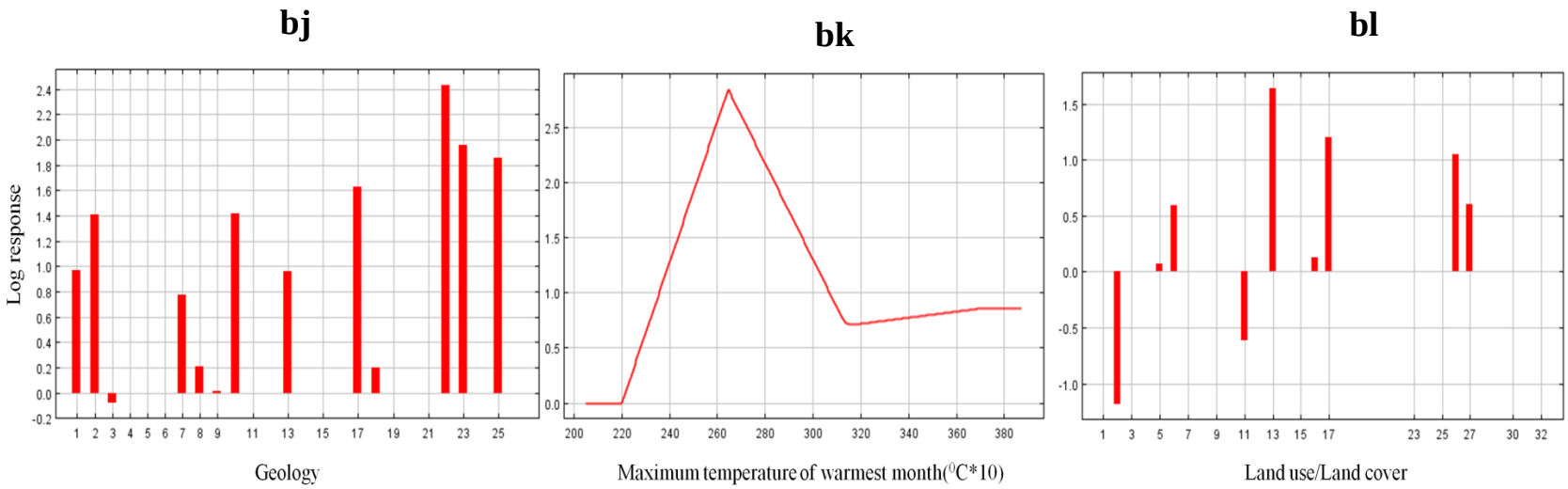


Appendices 4be and 4bf. The log response of *Eptesicus hottentotus* to (be) geology and (bf) land use/land cover when all locality records were used to build the final model. Geology and land use/land cover codes are exhibited in Table 4 and Table 3 respectively.

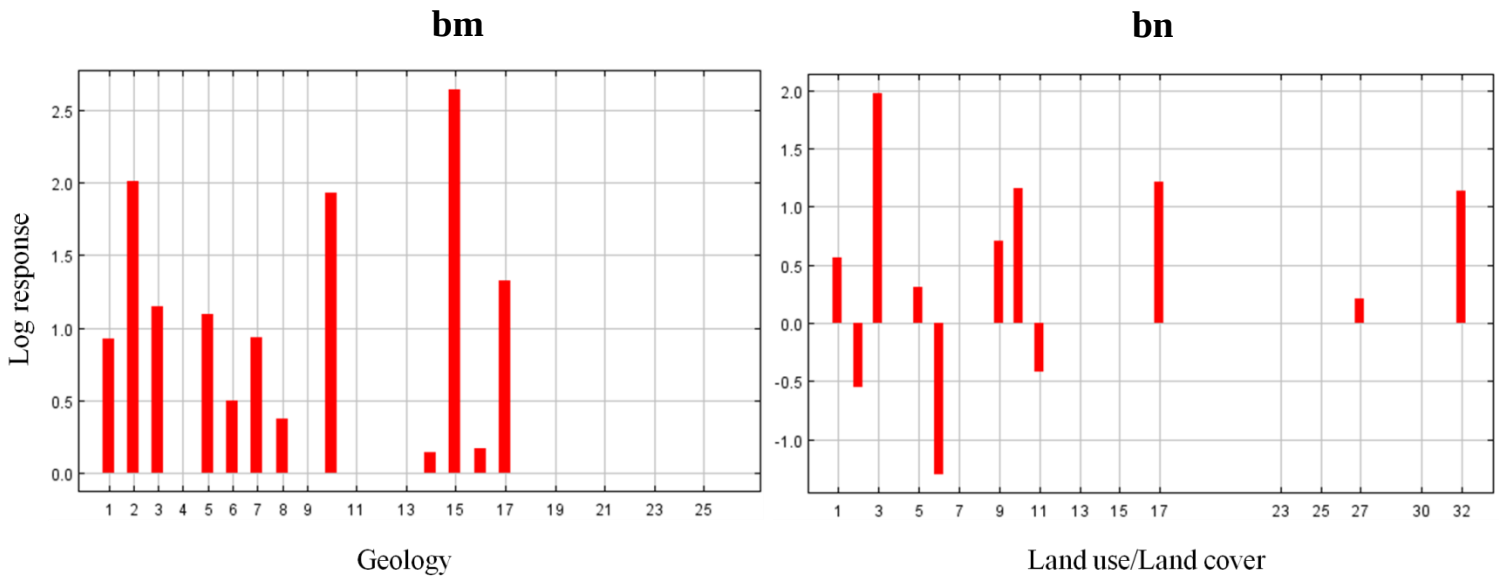
bg **bh** **bi**



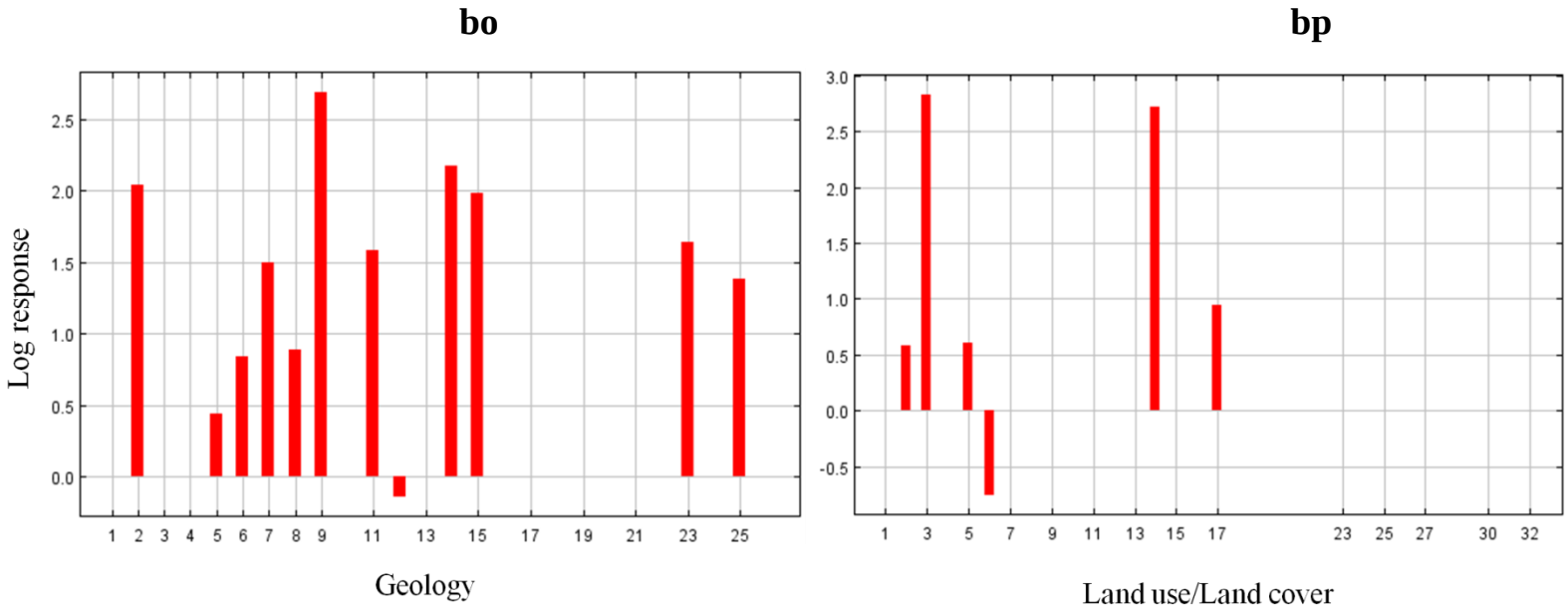
Appendices 4bg, 4bh, and 4bi. The log response of *Miniopterus natalensis* to (bg) geology, (bh) land use/land cover, and (bi) precipitation of coldest quarter when all locality records were used to build the final model. Geology and land use/land cover codes are displayed in Table 4 and Table 3 respectively.



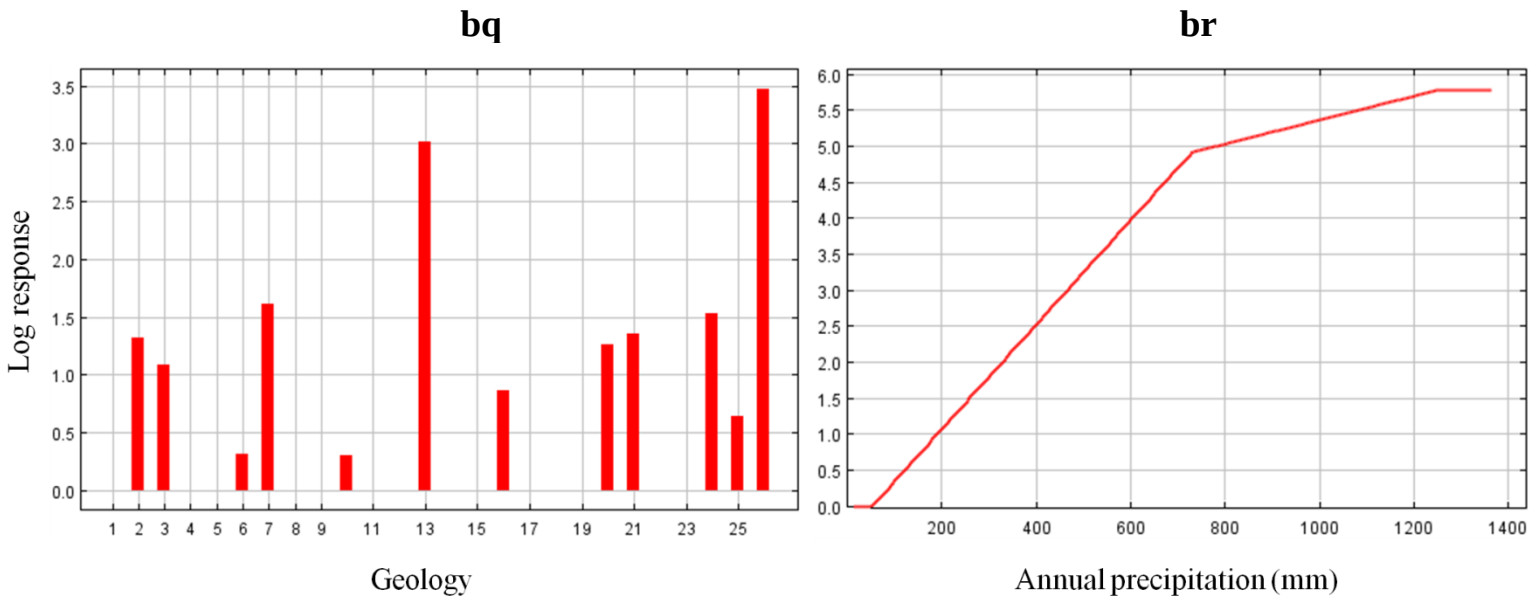
Appendices 4bj and 4bk. The log response of *Myotis tricolor* to (bj) geology, (bk) maximum temperature of warmest month, and (bl) land use/land cover when all locality records were used to build the final model. Geology and land use/land cover codes are illustrated in Table 4 and Table 3 respectively.



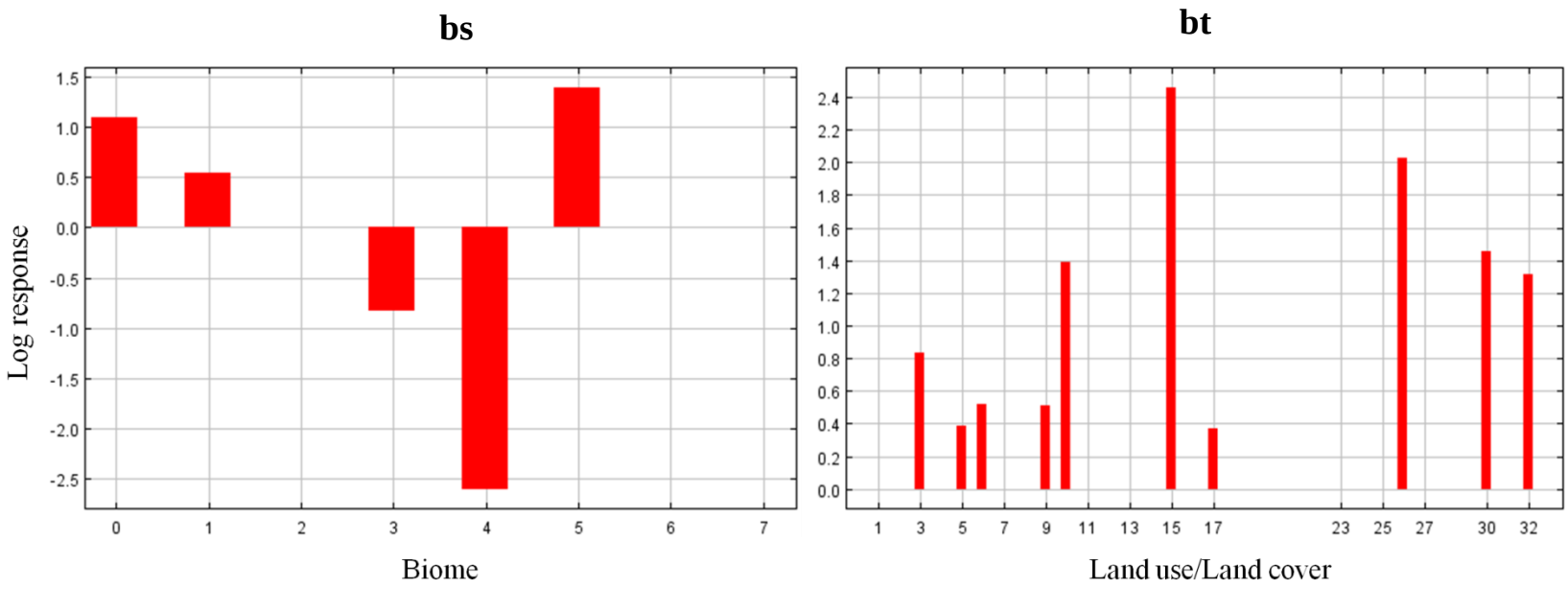
Appendices 4bm and 4bn. The log response of *Rhinolophus darlingi* to (bm) geology and (bn) land use/land cover when all locality records were used to build the final model. Geology and land use/land cover codes are displayed in Table 4 and Table 3 respectively.



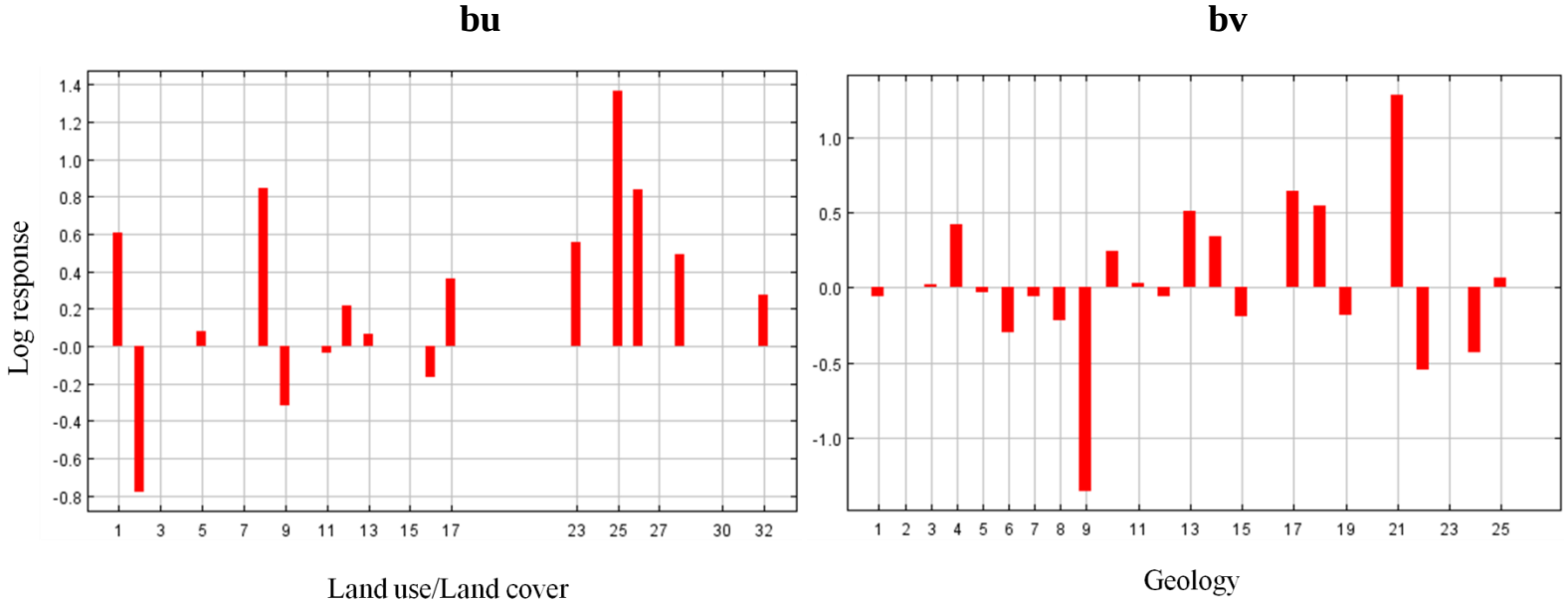
Appendices 4bo and 4bp. The log response of *Sauromys petrophilus* to (bo) geology and (bp) land use/land cover when all locality records were used to build the final model. Geology and land use/land cover codes are displayed in Table 4 and Table 3 respectively.



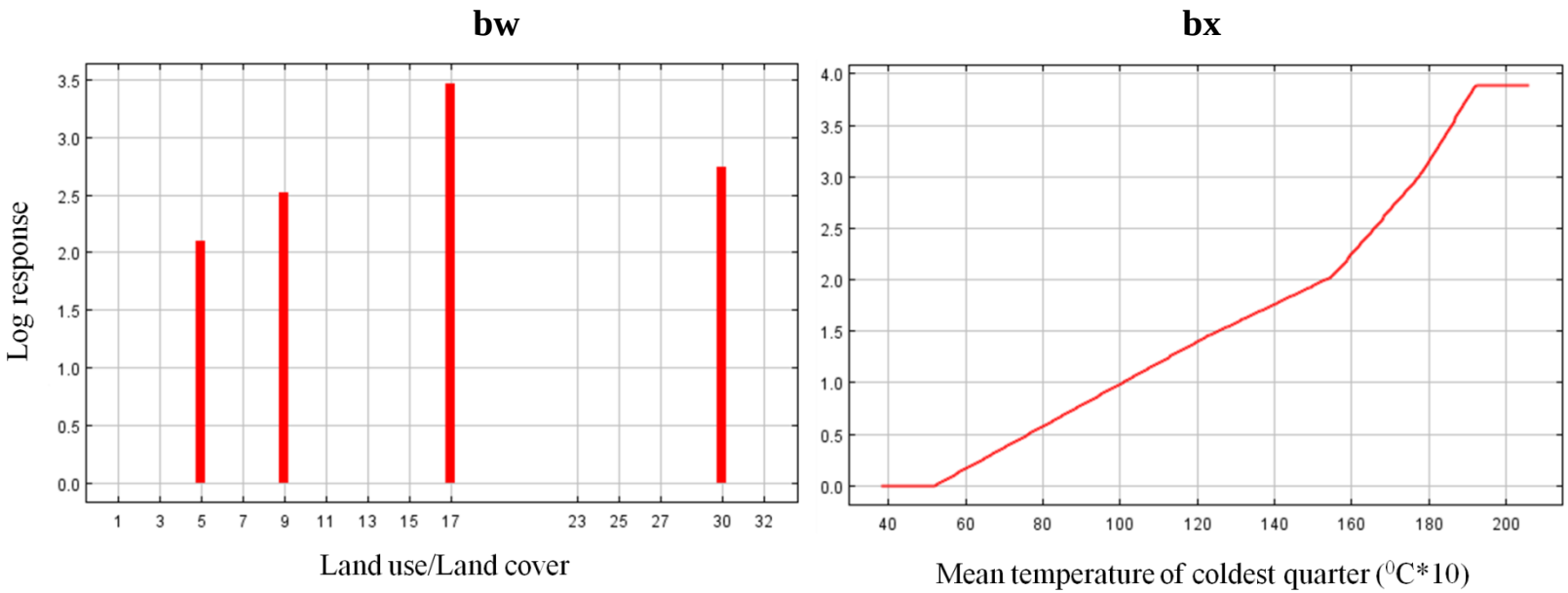
Appendices 4bq and 4br. The log response of *Rousettus aegyptiacus* to (bq) geology and (br) annual precipitation when all locality records were used to build the final model. Geology codes are displayed in Table 4.



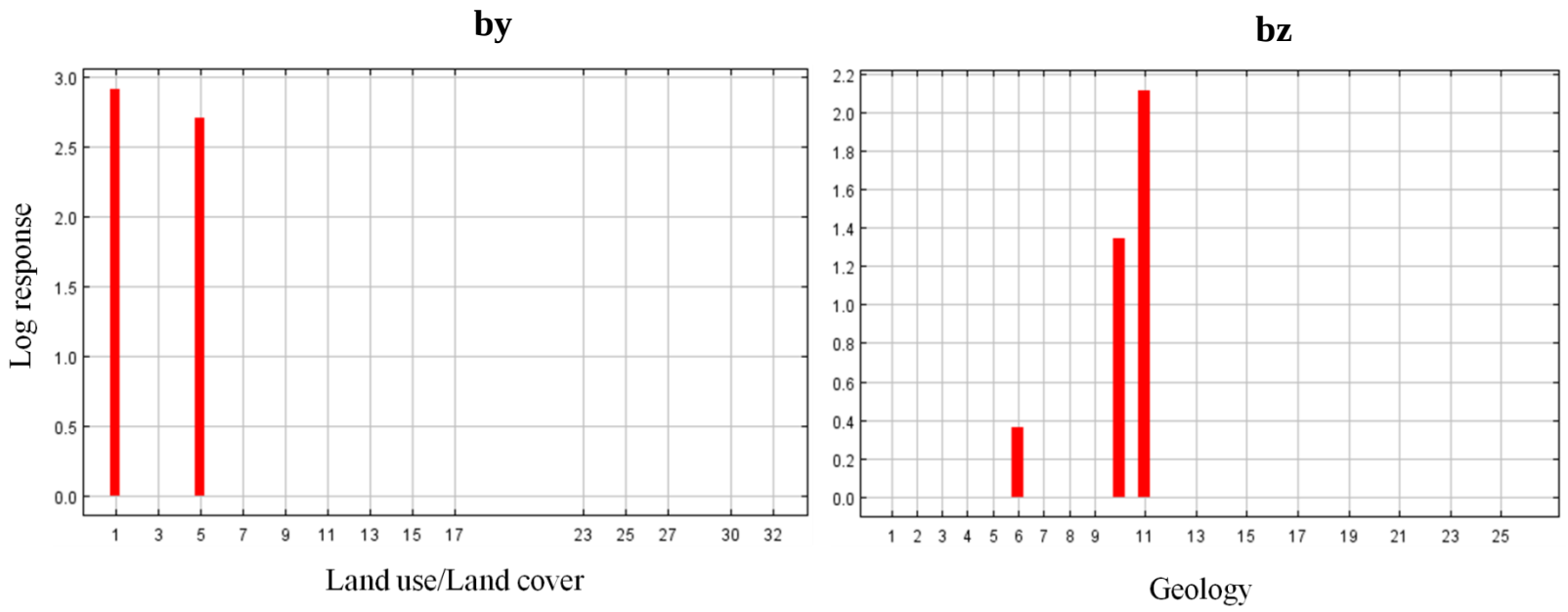
Appendices 4bs and 4bt. The log response of *Rousettus aegyptiacus* to (bs) biome and (bt) land use/land cover when all locality records were used to build the final model. Biome and land use/land cover codes are displayed in Table 2 and Table 3 respectively.



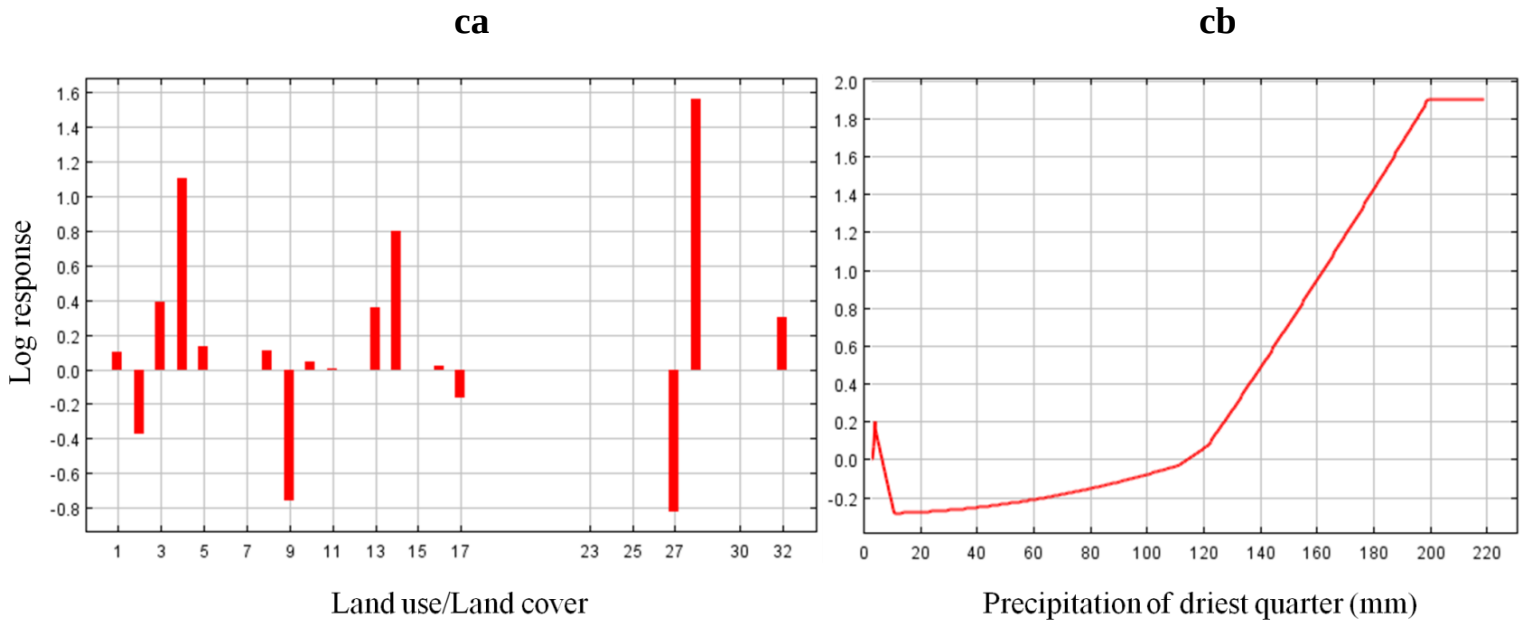
Appendices 4bu and 4bv. The log response of *Neoromicia capensis* to (bu) land use/land cover and (bv) geology when all locality records were used to build the final model. Land use/land cover and geology codes are displayed in Table 3 and Table 4 respectively.



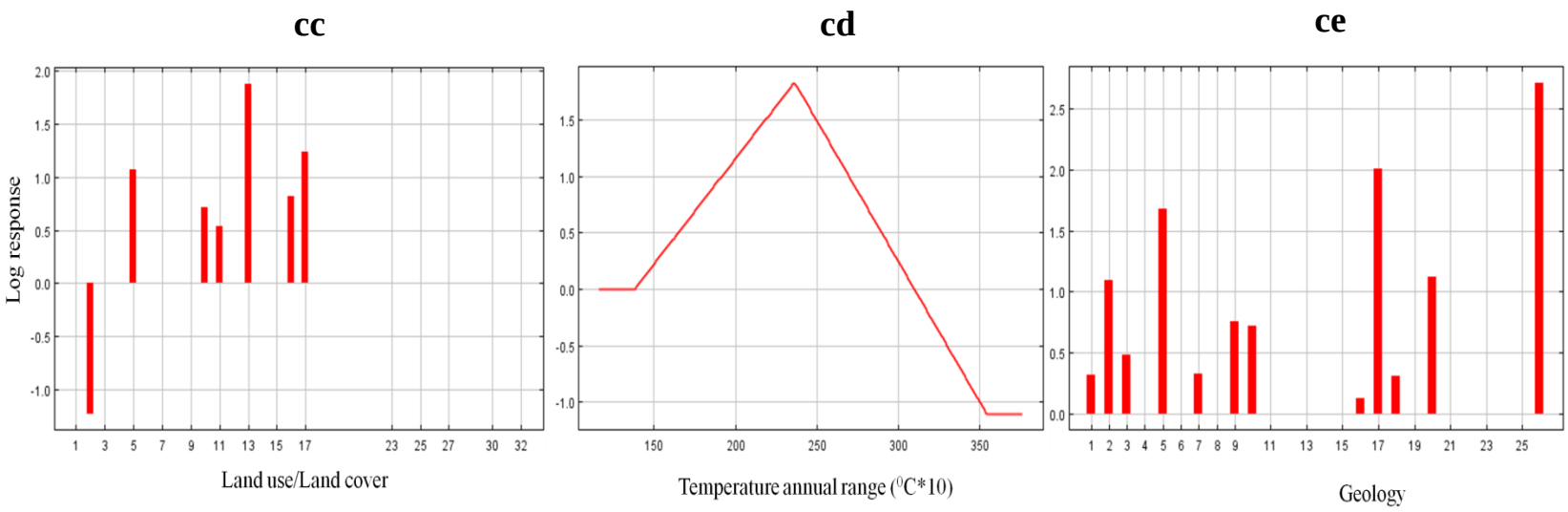
Appendices 4bw and 4bx. The log response of *Neoromicia zuluensis* to (bw) land use/land cover and (bx) mean temperature of coldest quarter when all locality records were used to build the final model. Land use/land cover codes are listed in Table 3.



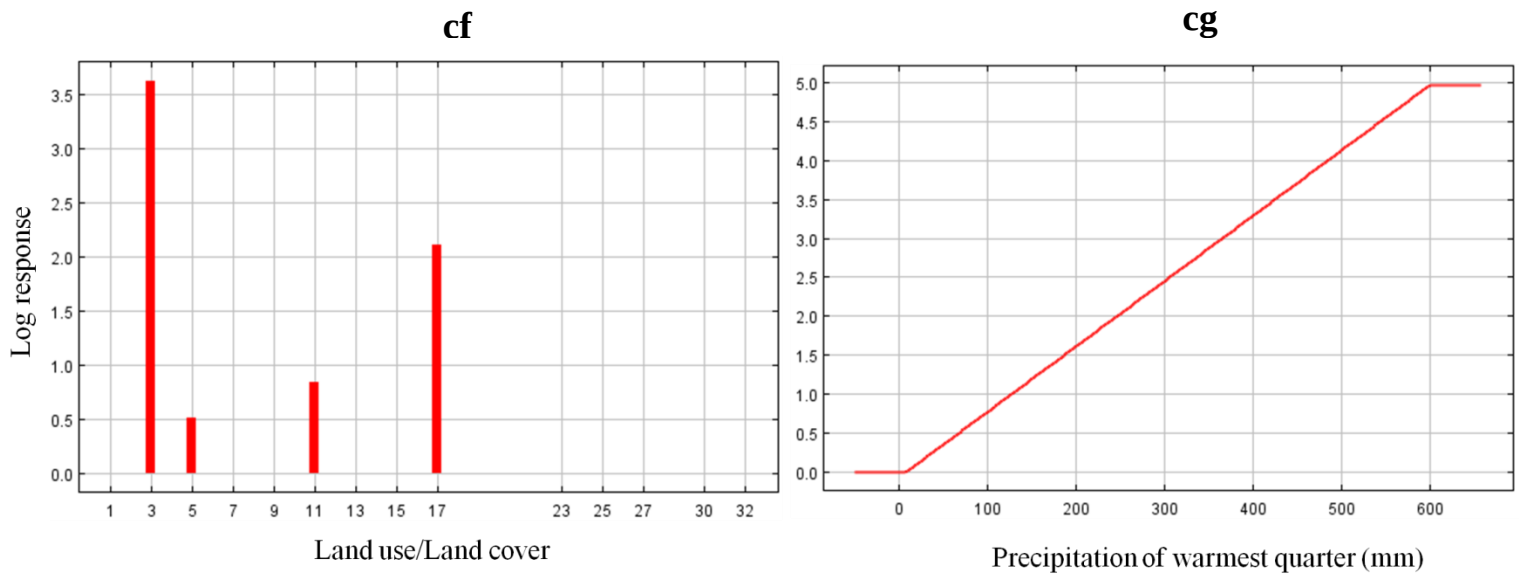
Appendices 4by and 4bz. The log response of *Rhinolophus denti* to (by) land use/land cover and (bz) geology when all locality records were used to build the final model. Land use/land cover and geology codes are given in Table 3 and Table 4 respectively.



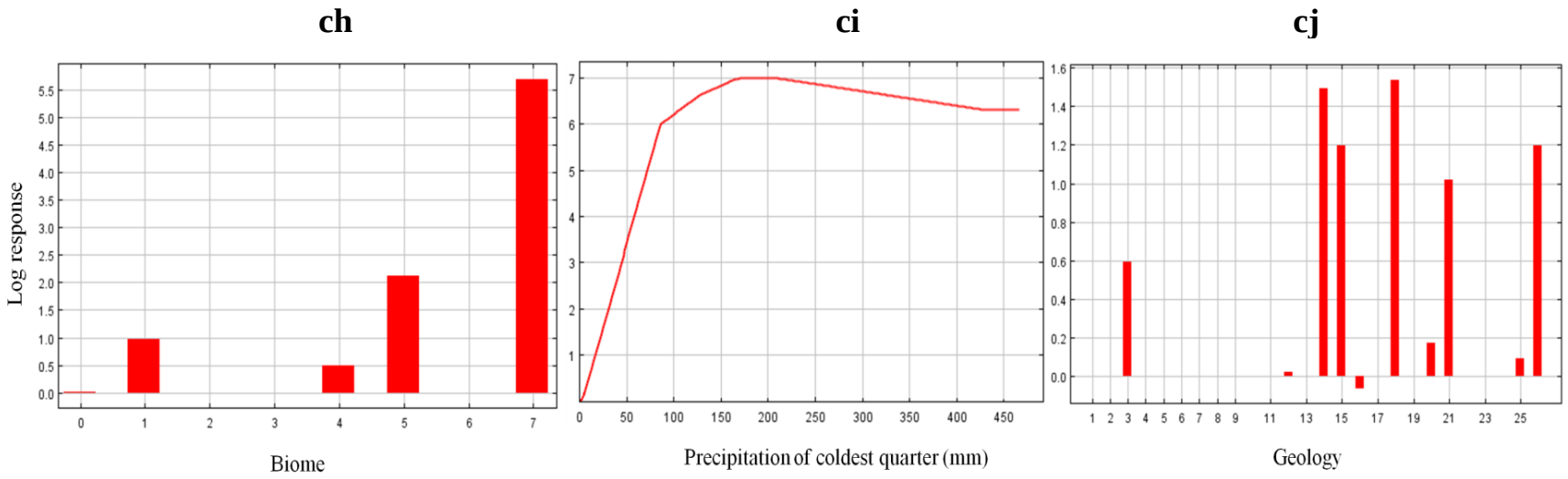
Appendices 4ca and 4cb. The log response of *Tadarida aegyptiaca* to (ca) land use/land cover and (cb) precipitation of driest quarter when all locality records were used to build the final model. Land use/land cover codes are displayed in Table 3.



Appendices 4cc, 4cd, and 4ce. The log response of *Taphozous mauritianus* to (cc) land use/land cover, (cd) temperature annual range, and (ce) geology when all locality records were used to build the final model. Land use/land cover and geology codes are exhibited in Table 3 and Table 4 respectively.Temperature annual range (i.e., the difference between the maximum temperature of warmest period and the minimum temperature of coldest period).



Appendices 4cf and 4cg. The log response of *Myotis welwitschii* to (cf) land use/land cover and (cg) precipitation of warmest quarter when all locality records were used to build the final model. Land use/land cover codes are displayed in Table 3.



Appendices 4ch, 4ci, and 4cj. The log response of *Rhinolophus capensis* to (ch) biome, (ci) precipitation of coldest quarter, and (cj) geology when all locality records were used to build the final model. Biome codes and geology codes are displayed in Table 2 and Table 4 respectively.

Appendix 5

Threat categories of the International Union for the Conservation of Nature (IUCN) Red List for all 57 bats species (Chiroptera) of South Africa. Modified from Friedman and Dally (2004).

Threat category	Number of species	Common name	Scientific name	Family
Critically Endangered	2	Percival's short-eared trident bat	*Cloeotis percivali*	Hipposideridae
		Rendall's serotine	*Neoromicia rendalli*	Vespertilionidae
Endangered	2	Swinny's horseshoe bat	*Rhinolophus swinnyi*	Rhinolophidae
		Damara woolly bat	*Kerivoula argentata*	Vespertilionidae
Vulnerable	6	Angolan wing-gland bat	*Cistugo seabrai*	Vespertilionidae
		Botswana long-eared bat	*Laephotis botswanae*	Vespertilionidae
		De Winton's long-eared bat	*Laephotis wintoni*	Vespertilionidae
		Larg-eared giant mastiff bat	*Otomops martiensseni*	Molossidae
		Blasius's horseshoe bat	*Rhinolophus blasii*	Rhinolophidae
		Thomas's house bat	*Scotophilus albofuscus*	Vespertilionidae
Near threatened	18	Lesueur's wing-gland bat	*Cistugo lesueuri*	Vespertilionidae
		Common butterfly bat	*Glauconycteris variegatus*	Vespertilionidae
		Lesser woolly bat	*Kerivoula lanosa*	Vespertilionidae
		Lesser long-fingered bat	*Miniopterus fraterculus*	Miniopteridae
		Natal long-fingered bat	*Miniopterus natalensis*	Miniopteridae
		Temminck's myotis	*Myotis tricolor*	Vespertilionidae
		Welwitsch's myotis	*Myotis welwitschii*	Vespertilionidae
		Anchieta's pipistrelle	*Hypsugo anchietae*	Vespertilionidae
		Rusty pipistrelle	*Pipistrellus rusticus*	Vespertilionidae
		Hairy slit-faced bat	*Nycteris hispida*	Nycteridae
		Wood's slit-faced bat	*Nycteris woodi*	Nycteridae
		Cape horseshoe bat	*Rhinolophus capensis*	Rhinolophidae
		Geoffroy's horseshoe bat	*Rhinolophus clivosus*	Rhinolophidae
		Darling's horseshoe bat	*Rhinolophus darlingi*	Rhinolophidae
		Dent's horseshoe bat	*Rhinolophus denti*	Rhinolophidae
		Rüppell's horseshoe bat	*Rhinolophus fumigatus*	Rhinolophidae
		Hildebrandt's horseshoe bat	*Rhinolophus hildebrandtii*	Rhinolophidae
		Lander's horseshoe bat	*Rhinolophus landeri*	Rhinolophidae
Least Concern	19	Ansorge's free-tailed bat	*Chaerephon ansorgei*	Molossidae
		Little free-tailed bat	*Chaerephon pumilus*	Molossidae

Threat category	Number of species	Common name	Scientific name	Family
		Wahlberg's epauletted fruit bat	*Epomophorus wahlbergi*	Pteropodidae
		Long-tailed serotine	*Eptesicus hottentotus*	Vespertilionidae
		Angolan free-tailed bat	*Mops condylurus*	Molossidae
		Midas free-tailed bat	*Mops midas*	Molossidae
		Cape serotine	*Neoromicia capensis*	Vespertilionidae
		Banana bat	*Neoromicia nana*	Vespertilionidae
		Zulu serotine	*Neoromicia zuluensis*	Vespertilionidae
		Egyptian slit-faced bat	*Nycteris thebaica*	Nycteridae
		Schlieffen's twilight bat	*Nycticeinops schlieffeni*	Vespertilionidae
		Dusky pipistrelle	*Pipistrellus hesperidus*	Vespertilionidae
		Bushveld horseshoe bat	*Rhinolophus simulator*	Rhinolophidae
		Egyptian rousette	*Rousettus aegyptiacus*	Pteropodidae
		Robert's flat-headed bat	*Sauromys petrophilus*	Molossidae
		Yellow-bellied house bat	*Scotophilus dinganii*	Vespertilionidae
		Green house bat	*Scotophilus viridis*	Vespertilionidae
		Egyptian free-tailed bat	*Tadarida aegyptiaca*	Molossidae
		Mauritian tomb bat	*Taphozous mauritianus*	Emballonuridae
Data Deficient	3	Peters's epauletted fruit bat	*Epomophorus crypturus*	Pteropodidae
		Sundevall's leaf-nosed bat	*Hipposideros caffer*	Hipposideridae
		Rufous bocagii	*Myotis bocagei*	Vespertilionidae
Extinct	0			

Appendix 6

Scientific names, Family, collection codes, year, locations, and geographic coordinates for bats recorded during a survey in the Northern Cape Province of South Africa from 2009-2010.

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
1	*Cistugo lesueuri*	Vespertilionidae	09.03.09VDK4(CRP)	2009	South Africa: Vanderkloof	24.2706	-30.0001
2	*Cistugo seabrai*	Vespertilionidae	16.01.10 Cs01 WL	2010	South Africa: Williston,Goedeverwgting Boerdery	20.9243	-31.4141
3	*Cistugo seabrai*	Vespertilionidae	16.11.09Cs1OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
4	*Cistugo seabrai*	Vespertilionidae	16.11.09Cs2OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
5	*Cistugo seabrai*	Vespertilionidae	27.02.09BNR3(BD)	2009	South Africa: Benfontein Nature Reserve	24.8215	-28.8223
6	*Cistugo seabrai*	Vespertilionidae	28.10.09ARC6(KAC2)	2009	South Africa: Augrabies National Park, Rest Camp	20.3374	-28.8931
7	*Cistugo seabrai*	Vespertilionidae	19.10.09KGA1(WHT)	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine, Watering hole	20.6247	-26.4343
8	*Hipposideros caffer*	Hipposideridae	18.11.09FFC9(GHC)	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
9	*Hipposideros caffer*	Hipposideridae	17.01.09FFE194(ORC)	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
10	*Miniopterous natalensis*	Vespertilionidae	21.01.09GNR21(BH)	2009	South Africa: Goegap NR, Bush huts	17.9543	-29.6871
11	*Miniopterous natalensis*	Vespertilionidae	10.03.09RF67(RNR)	2009	South Africa: Rolefontein NR	24.7598	-30.021
12	*Miniopterous natalensis*	Vespertilionidae	29.01.09SCP59(GNR)	2009	South Africa: Springbok Caravan Park	17.9086	-29.6791
13	*Miniopterous natalensis*	Vespertilionidae	18.11.09FFC6(GHC)	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
14	*Miniopterous natalensis*	Vespertilionidae	05.03.09RVR287(RNR1)	2009	South Africa: Rooipoort NR, Vaal River	24.2751	-28.6422
15	*Miniopterous natalensis*	Vespertilionidae	18.10.09KGA4(TRR)	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
16	*Miniopterus natalensis*	Vespertilionidae	11.03.09Mn1VDKDT1	2009	South Africa: Vanderkloof Dam, Service Tunel	24.725	-29.9973

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
17	*Miniopterus natalensis*	Vespertilionidae	11.03.09Mn2VDKDT1	2009	South Africa: Vanderkloof Dam, Service Tunel	24.725	-29.9973
18	*Miniopterus natalensis*	Vespertilionidae	16.11.09Mn1OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
19	*Miniopterus natalensis*	Vespertilionidae	16.11.09Mn2OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
20	*Miniopterus natalensis*	Vespertilionidae	23.01.09Mn1GBK	2009	South Africa: Goegap Nature Reserve, Bloukoker Boom-water	18.0164	-29.6393
21	*Miniopterus natalensis*	Vespertilionidae	25.02.09Mn1BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
22	*Neoromicia capensis*	Vespertilionidae	01.03.09Nca1RHB	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.2797	-28.6374
23	*Neoromicia capensis*	Vespertilionidae	01.03.09Nca2RHB	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.2797	-28.6374
24	*Neoromicia capensis*	Vespertilionidae	01.03.09Nca3RHB	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.2797	-28.6374
25	*Neoromicia capensis*	Vespertilionidae	01.03.09Nca4RHB	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.2797	-28.6374
26	*Neoromicia capensis*	Vespertilionidae	01.03.09Nca5RHB	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.2797	-28.6374
27	*Neoromicia capensis*	Vespertilionidae	02.03.09Nca6RHB	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.2797	-28.6374
28	*Neoromicia capensis*	Vespertilionidae	04.03.09Nca7RSD	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.1917	-28.6585
29	*Neoromicia capensis*	Vespertilionidae	04.03.09Nca8RSD	2009	South Africa: Rooiport Nature Reserve, Hunting Box	24.1917	-28.6585
30	*Neoromicia capensis*	Vespertilionidae	08.01.10 Nca 01 BF	2010	South Africa: Kenhardt	21.1451	-29.3556
31	*Neoromicia capensis*	Vespertilionidae	09.03.09Nca1VDKHR	2009	South Africa: Vanderkloof Holiday Resort	24.7543	-30.0009
32	*Neoromicia capensis*	Vespertilionidae	10.03.09Nca1RNRS1	2009	South Africa: Rolefontein Nature Reserve	24.7598	-30.021
33	*Neoromicia capensis*	Vespertilionidae	10.03.09Nca2RNRS1	2009	South Africa: Rolefontein Nature Reserve	24.7598	-30.021
34	*Neoromicia capensis*	Vespertilionidae	11.03.09Nc2VDKDps	2009	South Africa: Vanderkloof Dam, Eskom Power Station Buildings	24.7301	-29.9938
35	*Neoromicia*	Vespertilion	11.03.09Nc3VDKDps	2009	South Africa:	24.7301	-29.9938

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
	capensis	idae			Vanderkloof Dam, Eskom Power Station Buildings		
36	*Neoromicia capensis*	Vespertilionidae	16.01.09Nca1 ORW	2009	South Africa: Viooldrif, wier across the Orange River	17.532	-28.7016
37	*Neoromicia capensis*	Vespertilionidae	16.01.09Nca2 ORW	2009	South Africa: Viooldrif, wier across the Orange River	17.532	-28.7016
38	*Neoromicia capensis*	Vespertilionidae	16.01.09Nca3ORW	2009	South Africa: Viooldrif, wier across the Orange River	17.532	-28.7016
39	*Neoromicia capensis*	Vespertilionidae	16.01.09Nca4ORW	2009	South Africa: Viooldrif, wier across the Orange River	17.532	-28.7016
40	*Neoromicia capensis*	Vespertilionidae	16.01.09Nca5ORW	2009	South Africa: Viooldrif, wier across the Orange River	17.532	-28.7016
41	*Neoromicia capensis*	Vespertilionidae	16.01.09Nca6ORW	2009	South Africa: Viooldrif, wier across the Orange River	17.532	-28.7016
42	*Neoromicia capensis*	Vespertilionidae	17.01.10 Cs01 WL	2010	South Africa: Williston, Sak River	20.9044	-31.3601
43	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca1KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
44	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca2KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
45	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca3KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
46	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca4KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
47	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca5KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
48	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca6KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
49	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca7KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine	20.6121	-26.4718

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
					Restcamp		
50	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca8KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
51	*Neoromicia capensis*	Vespertilionidae	17.10.09Nca9KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
52	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca10ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
53	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca11ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
54	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca12ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
55	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca13ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
56	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca14ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
57	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca15ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
58	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca16ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
59	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca17ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
60	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca7ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
61	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca8ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
62	*Neoromicia capensis*	Vespertilionidae	18.01.09Nca9ORA	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
63	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca10KGA	2009	South Africa: Khalagadi	20.6121	-26.4718

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
					Transfrontier Park, Twee Riverine Restcamp		
64	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca11KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
65	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca13KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
66	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca14KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
67	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca15KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
68	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca16KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
69	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca17KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
70	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca18KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
71	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca19KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
72	*Neoromicia capensis*	Vespertilionidae	18.10.09Nca20KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
73	*Neoromicia capensis*	Vespertilionidae	19.01.09Nca18ORWA	2009	South Africa: Viooldrif, Wildthing Adventure camp along the Orange River	17.5039	-28.703
74	*Neoromicia capensis*	Vespertilionidae	22.01.09Nca1KGFH	2009	South Africa: Goegap Nature Reserve, Klien Geogap Farm House	18.0408	-29.3
75	*Neoromicia capensis*	Vespertilionidae	22.01.09Nca2KGFH	2009	South Africa: Goegap Nature Reserve, Klien	18.0408	-29.3

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
					Geogap Farm House		
76	*Neoromicia capensis*	Vespertilionidae	22.01.09Nca3KGFH	2009	South Africa: Goegap Nature Reserve, Klien Geogap Farm House	18.0408	-29.3
77	*Neoromicia capensis*	Vespertilionidae	22.01.09Nca4KGFH	2009	South Africa: Goegap Nature Reserve, Klien Geogap Farm House	18.0408	-29.3
78	*Neoromicia capensis*	Vespertilionidae	23.01.09Nca5GBK	2009	South Africa: Goegap Nature Reserve, Bloukoker Boom-water	18.0164	-29.6393
79	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca1 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
80	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca10 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
81	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca11 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
82	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca12 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
83	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca13 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
84	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca14 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
85	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca15 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
86	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca16BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
87	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca17BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
88	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca18BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
89	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca19BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
90	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca2 BRC	2009	South Africa: Benfontein Nature	24.821	-28.8242

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
					Reserve, Research Centre		
91	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca20BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
92	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca21BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
93	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca22BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
94	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca23BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
95	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca24BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
96	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca25BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
97	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca26BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
98	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca27BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
99	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca28BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
100	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca29BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
101	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca3 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
102	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca30BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
103	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca31BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
104	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca32BRC	2009	South Africa: Benfontein Nature Reserve, Research	24.821	-28.8242

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
					Centre		
105	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca33BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
106	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca4 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
107	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca5 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
108	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca6 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
109	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca7 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
110	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca8 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
111	*Neoromicia capensis*	Vespertilionidae	25.02.09Nca9 BRC	2009	South Africa: Benfontein Nature Reserve, Research Centre	24.821	-28.8242
112	*Neoromicia capensis*	Vespertilionidae	26.02.09Nca34BFP	2009	South Africa: Benfontein Nature Reserve, Forested patch about 1 km from the Research Centre	24.8355	-28.8223
113	*Neoromicia capensis*	Vespertilionidae	27.01.09Nca7SBS	2009	South Africa: Springbok, Bergsig Sewage Works	17.8603	-29.6438
114	*Neoromicia capensis*	Vespertilionidae	28.01.09Nca10SS	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097
115	*Neoromicia capensis*	Vespertilionidae	28.01.09Nca11SS	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097
116	*Neoromicia capensis*	Vespertilionidae	28.01.09Nca8SS	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097
117	*Neoromicia capensis*	Vespertilionidae	28.01.09Nca9SS	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097
118	*Neoromicia capensis*	Vespertilionidae	28.02.09Nca35BPS	2009	South Africa: Benfontein Nature Reserve, Picnic site	24.8214	-28.8274
119	*Neoromicia*	Vespertilion	28.02.09Nca36BPS	2009	South Africa:	24.8214	-28.8274

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
	capensis	idae			Benfontein Nature Reserve, Picnic site		
120	*Neoromicia capensis*	Vespertilionidae	28.02.09Nca37BPS	2009	South Africa: Benfontein Nature Reserve, Picnic site	24.8214	-28.8274
121	*Neoromicia capensis*	Vespertilionidae	28.02.09Nca38BPS	2009	South Africa: Benfontein Nature Reserve, Picnic site	24.8214	-28.8274
122	*Neoromicia capensis*	Vespertilionidae	28.02.09Nca39BPS	2009	South Africa: Benfontein Nature Reserve, Picnic site	24.8214	-28.8274
123	*Neoromicia capensis*	Vespertilionidae	28.02.09Nca40BPS	2009	South Africa: Benfontein Nature Reserve, Picnic site	24.8214	-28.8274
124	*Neoromicia capensis*	Vespertilionidae	28.10.09Nca1AUG	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.3374	-28.5926
125	*Neoromicia capensis*	Vespertilionidae	31.10.09Nca2AUG	2009	South Africa: Augrabies National Park, Bloupunts House	20.1707	-28.5215
126	*Neoromicia capensis*	Vespertilionidae	13.03.09BFB2(PJF)	2009	South Africa:Petrusville, Joria Farm	24.6532	-30.0918
127	*Neoromicia capensis*	Vespertilionidae	06.10.09FF1(ORL)	2009	South Africa: Oorlogskloof NR	19.4518	-31.5076
128	*Neoromicia capensis*	Vespertilionidae	28.01.09SSW11(SES)	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097
129	*Pipistrellus rueppellii*	Vespertilionidae	26.02.09PNR4(BFP)	2009	South Africa: Benfontein Nature Reserve	24.8355	-28.8223
130	*Pipistrellus rueppellii*	Vespertilionidae	27.01.09NR27(SBS)	2009	South Africa: Springbok, Bergsig Sewage Works	17.8603	-29.6438
131	*Rhinolophus clivosus*	Rhinolophidae	24.01.09Rcl1 GO	2009	South Africa: Goegap Nature Reserve, Main offices	18.0082	-29.6752
132	*Rhinolophus clivosus*	Rhinolophidae	29.10.09Rcc1AUG	2009	South Africa: Augrabies National Park, Eco Corner	20.2863	-28.5491
133	*Rhinolophus clivosus*	Rhinolophidae	29.01.09SCP53(GNR)	2009	South Africa: Springbok Caravan Park	17.9086	-29.6791
134	*Rhinolophus denti*	Rhinolophidae	07.03.09RHD121(RNR)	2009	South Africa: Rooipoort NR, Hoffman's Pan	24.1629	-28.7047
135	*Rhinolophus sp.*	Rhinolophidae	14.01.10 R?08 Un	2010	South Africa: Uintjiesberg Farm, Carnarvon	22.5364	-30.8255
136	*Rhinolophus sp.*	Rhinolophidae	14.01.10 R?16 Un	2010	South Africa: Uintjiesberg Farm, Carnarvon	22.5364	-30.8255
137	*Rhinolophus*	Rhinolophid	14.01.10 R?18 Un	2010	South Africa:	22.5364	-30.8255

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
	sp.	ae			Uintjiesberg Farm, Carnarvon		
138	*Rhinolophus sp.*	Rhinolophidae	14.01.10 R?20 Un	2010	South Africa: Uintjiesberg Farm, Carnarvon	22.5364	-30.8255
139	*Rhinolophus sp.*	Rhinolophidae	14.01.10 R?22 Un	2010	South Africa: Uintjiesberg Farm, Carnarvon	22.5364	-30.8255
140	*Rhinolophus sp.*	Rhinolophidae	16.01.09R?1 ORC	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
141	*Rhinolophus sp.*	Rhinolophidae	16.01.09R?2 ORC	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
142	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?10OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
143	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?11OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
144	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?12OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
145	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?13OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
146	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?14OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
147	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?15OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
148	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?16OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
149	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?17OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
150	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?1OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
151	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?2OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
152	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?3OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
153	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?4OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
154	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?5OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
155	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?6OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
156	*Rhinolophus*	Rhinolophid	16.11.09R?7OR	2009	South Africa:	17.1927	-28.2517

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
	sp.	ae			Viooldrift, Orange River, Cave		
157	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?8OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
158	*Rhinolophus sp.*	Rhinolophidae	16.11.09R?9OR	2009	South Africa: Viooldrift, Orange River, Cave	17.1927	-28.2517
159	*Rhinolophus sp.*	Rhinolophidae	17.01.09R?3 ORC	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
160	*Rhinolophus sp.*	Rhinolophidae	17.01.09R?4 ORC	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
161	*Rhinolophus sp.*	Rhinolophidae	17.01.09R?5 ORC	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
162	*Rhinolophus sp.*	Rhinolophidae	17.01.09R?6 ORC	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
163	*Rhinolophus sp.*	Rhinolophidae	17.01.09R?8 ORC	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
164	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca10GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
165	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca1GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
166	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca2GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
167	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca3GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
168	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca4GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
169	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca5GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
170	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca6GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
171	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca7GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
172	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca8GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
173	*Rhinolophus sp.*	Rhinolophidae	18.11.09Rca9GH	2009	South Africa: GoodHouse/Hankeries mines	18.1284	-28.9431
174	*Rhinolophus sp.*	Rhinolophidae	22.01.09KFH413(GNR)	2009	South Africa: Goegap Nature Reserve, Klien Geogap Farm House	18.0408	-29.3
175	*Sauromys*	Molossidae	18.01.09Sp1ORA	2009	South Africa:	17.5897	-28.6956

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
	petrophilus				Viooldrif, Acquacade camp along the Orange River		
176	*Sauromys petrophilus*	Molossidae	26.01.09Sp1GCW	2009	South Africa: Springbok, Golf course	17.907	-29.6856
177	*Sauromys petrophilus*	Molossidae	27.01.09Sp2SBS	2009	South Africa: Springbok, Bergsig Sewage Works	17.8603	-29.6438
178	*Sauromys petrophilus*	Molossidae	27.01.09Sp3SBS	2009	South Africa: Springbok, Bergsig Sewage Works	17.8603	-29.6438
179	*Sauromys petrophilus*	Molossidae	16.01.09OR45(ORW)	2009	South Africa: Viooldrift, Orange River, over water	17.532	-28.7016
180	*Sauromys petrophilus*	Molossidae	18.01.09OR120(ORA)11	2009	South Africa: Viooldrif, Acquacade camp along the Orange River	17.5897	-28.6956
181	*Sauromys petrophilus*	Molossidae	17.01.09FFE6(ORC)	2009	South Africa: Viooldrif, a long the Orange River, acave	17.1927	-28.2517
182	*Sauromys petrophilus*	Molossidae	27.01.09NR25(SBS)	2009	South Africa: Springbok, Bergsig Sewage Works	17.8603	-29.6438
183	*Sauromys petrophilus*	Molossidae	28.01.09NR2(GBH)	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097
184	*Sauromys petrophilus*	Molossidae	24.01.09NR14(GMO)	2009	South Africa: Goegap NR, main offices	18.0082	-29.6752
185	*Sauromys petrophilus*	Molossidae	31.10.09ABH3(BPH)	2009	South Africa: Augrabies National Park, Bloupunts House	20.2019	-28.8708
186	*Sauromys petrophilus*	Molossidae	07.03.09RHD2(RNR)	2009	South Africa: Rooipoort NR, Hoffman's Pan	24.1629	-28.7047
187	*Sauromys petrophilus*	Molossidae	11.03.09VDP2(VPS)	2009	South Africa:Vanderkloof Dam	24.2706	-30.0001
188	*Sauromys petrophilus*	Molossidae	06.03.09RVR562(RNR2)	2009	South Africa: Rooipoort NR, Vaal River	24.0824	-28.66
189	*Sauromys petrophilus*	Molossidae	25.01.09BWS3(GNR)	2009	South Africa: Goegap NR, Brakwater Spring	18.0107	-29.2505
190	*Sauromys petrophilus*	Molossidae	28.01.09SSW239(SES)	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097
191	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 01 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
192	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 02 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
193	*Tadarida*	Molossidae	06.01.10 Ta 03 BF	2010	South Africa:	20.6297	-30.056

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
	aegyptiaca				Bastiaanskolk Farm, Kenhardt		
194	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 04 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
195	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 05 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
196	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 06 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
197	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 07 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
198	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 08 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
199	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 09 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
200	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 10 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
201	*Tadarida aegyptiaca*	Molossidae	06.01.10 Ta 11 BF	2010	South Africa: Bastiaanskolk Farm, Kenhardt	20.6297	-30.056
202	*Tadarida aegyptiaca*	Molossidae	13.03.09Ta1PTF	2009	South Africa: Petrusville, Juria Farm	24.6532	-30.0918
203	*Tadarida aegyptiaca*	Molossidae	13.03.09Ta2PTF	2009	South Africa: Petrusville, Juria Farm	24.6532	-30.0918
204	*Tadarida aegyptiaca*	Molossidae	13.03.09Ta3PTF	2009	South Africa: Petrusville, Juria Farm	24.6532	-30.0918
205	*Tadarida aegyptiaca*	Molossidae	13.03.09Ta4PTF	2009	South Africa: Petrusville, Juria Farm	24.6532	-30.0918
206	*Tadarida aegyptiaca*	Molossidae	13.03.09Ta5PTF	2009	South Africa: Petrusville, Juria Farm	24.6532	-30.0918
207	*Tadarida aegyptiaca*	Molossidae	13.03.09Ta6PTF	2009	South Africa: Petrusville, Juria Farm	24.6532	-30.0918
208	*Tadarida aegyptiaca*	Molossidae	13.03.09Ta7PTF	2009	South Africa: Petrusville, Juria Farm	24.6532	-30.0918
209	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta10KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
210	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta11KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
211	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta1KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
212	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta2KGA	2009	South Africa: Khalagadi	20.6121	-26.4718

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
					Transfrontier Park, Twee Riverine Restcamp		
213	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta3KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
214	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta4KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
215	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta5KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
216	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta6KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
217	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta7KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
218	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta8KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
219	*Tadarida aegyptiaca*	Molossidae	17.10.09Ta9KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
220	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta12KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
221	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta13KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
222	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta14KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
223	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta15KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine	20.6121	-26.4718

No	Speceis name	Family	Col. code	Col. year	Loc. name	Long. (decimal degrees)	Lat. (decimal degrees)
					Restcamp		
224	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta16KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
225	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta17KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
226	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta18KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
227	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta19KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
228	*Tadarida aegyptiaca*	Molossidae	18.10.09Ta20KGA	2009	South Africa: Khalagadi Transfrontier Park, Twee Riverine Restcamp	20.6121	-26.4718
229	*Tadarida aegyptiaca*	Molossidae	30.10.09Ta2AUG	2009	South Africa: Augrabies National Park, Cave	20.1707	-28.5215
230	*Tadarida aegyptiaca*	Molossidae	26.01.09GGW32(SBG)	2009	South Africa: Springbok, Golf course	17.907	-29.6856
231	*Tadarida aegyptiaca*	Molossidae	27.01.09NR35(SBS)	2009	South Africa: Springbok, Bergsig Sewage Works	17.8603	-29.6438
232	*Tadarida aegyptiaca*	Molossidae	24.01.09NR26(GMO)	2009	South Africa: Goegap NR, main offices	18.0082	-29.6752
233	*Tadarida aegyptiaca*	Molossidae	29.01.09SCP14(GNR)	2009	South Africa: Springbok Caravan Park	17.9086	-29.6791
234	*Tadarida aegyptiaca*	Molossidae	07.03.09RHD150(RNR)	2009	South Africa: Rooipoort NR, Hoffman's Pan	24.1629	-28.7047
235	*Tadarida aegyptiaca*	Molossidae	05.03.09RVR643(RNR 1)	2009	South Africa: Rooipoort NR, Vaal River	24.2751	-28.6422
236	*Tadarida aegyptiaca*	Molossidae	22.01.09KFH1(GNR)	2009	South Africa: Goegap Nature Reserve, Klien Geogap Farm House	18.0408	-29.3
237	*Tadarida aegyptiaca*	Molossidae	28.01.09SSW2(SES)	2009	South Africa: Springbok, Sewage Works, southwest Springbok	17.9003	-29.7097